Bayesian Belief Network (BBN)-based Advisory System Development for Steam Generator Replacement Project Management

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Abstract

The growing need for improved project management technique points to the usefulness of a knowledge-base advisory system to help project managers understand current and future project status and optimize decisions based upon the project performances. The work here demonstrates the framework of an advisory system with improved ability in project management. Based upon the literature survey and discussion with relevant experts, the Bayesian Belief Network (BBN) approach was selected to model the steam generator replacement project management problem, where the situation holds inherently large uncertainty and complexities, since it has a superior ability to treat complexities, uncertainty management, systematic decision making, inference mechanism, knowledge representation and model modification for newly acquired knowledge.

Two modes of advisory system have been constructed. As the first mode, the predictive mode has been developed, which can predict future project performance state probability distributions, assuming no intervening management action. The second mode is the advisory mode, which can identify the optimal action among alternatives based upon the expected net benefit values that are incorporating two important components: 1) expected immediate net benefits at post-action time, and 2) the expected long term benefit (or penalty) at scheduled project completion time.

During the work, new indices for important variables have been newly developed for effective and efficient project status monitoring. With application of developed indices to the advisory system, the long term benefit (or penalty) found to be the most important factor in determining the optimal action by the project management during the decision making process and was confirmed by the domain experts. As a result, the effort has been focused on incorporating the long term benefit (or penalty) concept in order to provide more reliable and accurate advice to the project managers. In addition, in order to facilitate the communication between the BBN models and the users, an interface program has been developed using the Visual Basic language.

Thesis supervisor: Michael W. Golay, Professor of Nuclear Engineering Department
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CHAPTER 1.
INTRODUCTION

1.1 Project management

A project is defined in the PMI (Project Management Institute) book as "*A temporary endeavor undertaken to create a unique product or service*". (Duncan W. R., 1996) In this definition, 'temporary' means that every project has a definite beginning and a definite ending, and 'unique' means that the product or service in a project is different in some distinguishing way from all similar products or services in other projects. Usually the term 'project' is used as a one-time activity with a well-defined set of desired end products that can be tangible and/or intangible materials. "*Although the construction of Boulder Dam or Edison's invention of the light bulb were the projects by the sensible definition, the Manhattan Project is usually said to be the first modern project in the management concept.*" (Meredith Jack R., S. J. Mantel Jr., 2000) A project can be divided into subtasks that must be accomplished in order to achieve the pre-specified project goals and therefore is complex enough that the subtasks require careful coordination and control in terms of timing, cost and performance. Often, a project itself must be coordinated with other projects being performed by the same parent organization.

What is the definition of 'project management'? It could found in many places, but the widely used definition from the PMI book says "*Project management is the application of knowledge, skills, tools and techniques to project activities in order to meet or exceed stakeholder needs and expectations from a project*". (Duncan W. R., 1996) Generally, the term 'project management' describes the management of following project components that are considered to be key factors to the project's success. (Duncan W. R., 1996)

- *Project time management, describes the processes required to ensure timely completion of the project.*
- *Project cost management, describes the processes required to ensure project completion within the approved budget.*
- *Project quality management, describes the processes required to ensure satisfaction of the needs for which it was undertaken.*
- *Project scope management, describes the processes required to ensure the inclusion of all work required to complete the project successfully.*
- *Project human resource management, describes the processes to ensure the most effective use of the people involved in the project.*
- *Project communications management, describes the processes to ensure timely and appropriate generation, collection, dissemination, storage and disposition of project information.*
- *Project risk management, describes the processes concerned with identifying, analyzing and responding the project risk.*
- *Project procurement management, describes the processes required to acquire goods and services from inside and outside the performing organization.*

Why do we need project management? There are a lot of actual experiences showing the advantages of project management. Some of advantages are better control of the project, better customer relationships, an increase in the project's return on investment, shorter project time, lower costs, higher quality and reliability, sharper orientation toward results and higher worker morale. (Davis E. W., 1974 and IBBS, C. W., Y-H Kwak, 1997) On the negative side, however, there may be several disadvantages of project management, such as greater organizational complexity, more management difficulties and low personnel utilization. These disadvantages stem from the same source as its advantages. Therefore the disadvantages seem to be the price one should pay in order to obtain the advantages. On the whole, the balance weighs in favor of project management, if the work is done appropriately for a project.

1.1.1 Steam generator replacement project

Nuclear Power Plants (NPPs) in the US were built from 1960s to 1990s. Initially they obtained licenses for 30 or 40 years of operation from the Nuclear Regulatory Commission (NRC). Therefore the time when they should be decommissioned or re-licensed is coming for some of these NPPs. The steam generator is the most important and vulnerable component in the NPP and is the component that most concerns the NRC when considering license renewal for continued plant operation. During the 30- or 40-year initial license period of a Pressurized Water Reactor (PWR), replacement of the steam generators is likely at least once. Degradation of the tubes inside the steam generator causes its expected life to be much less than originally designed. Eventually, when about 15% of the 3000+ tubes in the steam generator have become clogged and stops the primary coolant from flowing, heat transfer properties deteriorate such that replacement of the steam generator is needed for the plant to maintain full power. At this time, it is determined that it is more cost effective to replace the steam generators than the long-term effect of clogged tubes. Therefore, steam generator replacement projects have already been performed in some NPPs, such as Catawba Nuclear Station Unit 1 and McGuire Nuclear Station Units 1 and 2, are currently underway in some NPPs and will be carried out in other NPPs in the near future.

The scope of the replacement project involves removal and replacement of the steam generators; providing necessary special handling equipments, removing or modifying existing plant structures and rerouting piping and electrical systems connected to the steam generators. The steam generators are housed inside the reactor buildings within cubicles with partially removable steel walls and domes. Air handling units and associated steel platforms are located above the enclosure domes. Piping systems that are connected to the steam generators have to be severed before the steam generators can be unbolted from the support structures holding them in place. While the piping systems are being severed, the air handling units, associated platforms, enclosure domes and walls have to be removed. In fact, a major portion of the reactor building has to be disassembled to remove the steam generators. In order to lift and transport the removed steam generators out of containment, a special Temporary Lifting Device (TLD) should be mounted to the station's polar crane inside the reactor building. Once the steam generator is lifted, it has to be laid down and transported out the reactor building equipment hatch. This is accomplished by constructing a rail system that spans from the interior of the reactor building through the equipment hatch and extends to the outside of the reactor building in order to complete the transfer of the steam generators from the cavities to the exterior handling hoist. This handling system requires modification of the existing ramp to the equipment hatch and installation of a crane near the base of the ramp to facilitate materials and equipment movement. Additional activities associated with removing the steam generators include building scaffolding, installing temporary power, lighting and services as well as installing lead shielding to reduce worker exposure to radiation, removal/replacement/modification to the different piping systems including feedwater, main steam, blowdown and nuclear sampling. Once the removal of the old steam generators has been accomplished, the new steam generators can be moved into the reactor building and fixed inside the steam generator vault. This scope of the steam generator replacement project is summarized below:

- Old steam generator is moved in containment
- Old steam generator is lowered for removal from containment
- New steam generator is moved through the equipment hatch into containment
- New steam generator is lifted in containment
- New steam generator is fixed in position

Figure 1-1 shows a new steam generator being lifted for placement in the steam generator vault as the last step of the project.

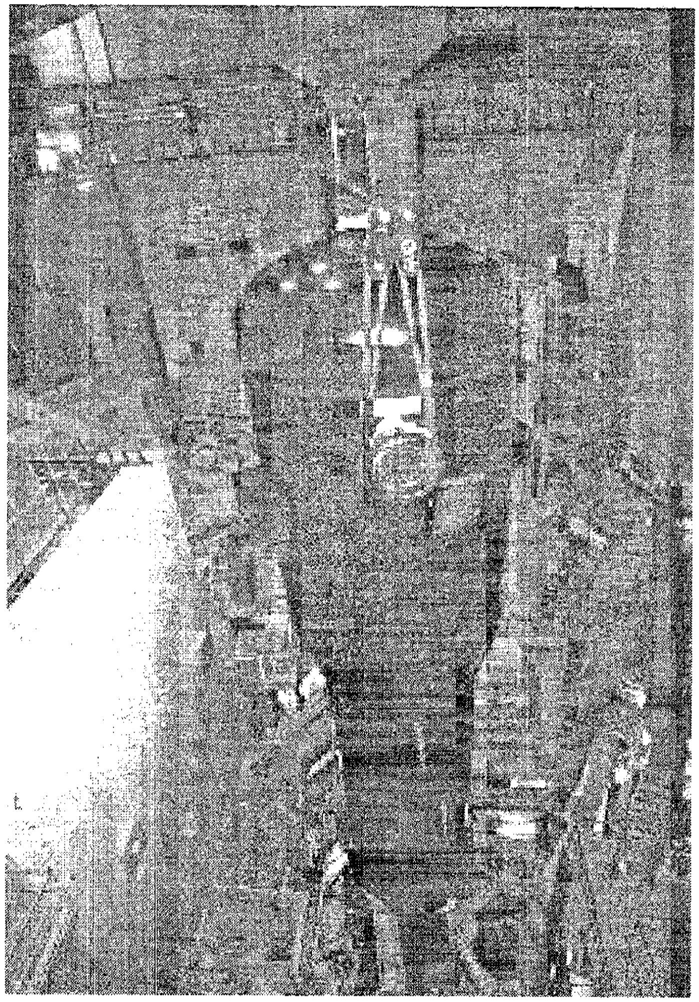


Figure 1-1. Installation of new steam generator into vault
(http://www.virtualnucleartourist.com)

1.2 Expert systems

A knowledge-based system is a general term for a computer system that embodies an explicit representation of knowledge of particular problem domain human experts. And an expert system is known as a subset of knowledge-based system that can analyze, solve, diagnosis, advise and so on. An expert system has a number of different names, e.g., automated advisors, computerized assistants or virtual consultants. Two representative definitions on expert systems are given as follows.

"Expert systems are machines that think and reason as an expert would in a particular domain. For example, a medical diagnosis expert system would request as input the patient's symptoms, test results and other relevant factors; using these as pointers, it would search its data for information that might lead to the identification of the illness. A true expert system not only performs traditional computer functions of handling large amounts of data, but also manipulates that data so the output is a meaningful answer to less than fully specified questions." (Stevens L., 1984)

"Expert systems – a class of computer programs that can advise, analyze, categorize, communicate, consult, design, diagnose, explore, forecast, form concepts, identify, interpret, justify, learn, manage, monitor, plan, present, retrieve, schedule, test and tutor. They address problems normally thought to require human specialists for their solution." (Morris W. Firebaugh, 1988)

The basic concept of an (knowledge-based) expert system consists of two parts: 1) supplying facts to the expert system, and 2) receiving expert advice in response from the knowledge that represents real human experts in a particular problem domain. Internally, the expert system consists of two main components: 1) the knowledge base, and 2) the inference engine. The knowledge base contains knowledge elicited from real human experts and the inference engine uses knowledge to draw conclusions from facts supplied by the user for the particular problem domain. Generally, most expert systems have the following common features: 1) explicit representation of particular problem domain knowledge, 2) inference mechanism (or engine), 3) provision for reasoning with uncertain evidence and knowledge and 4) provision of justification, explanation and other user support.

An expert system has a number of attractive features. It is an accumulation of the knowledge of multiple human experts and its expertise is readily available to anyone who wants it on any suitable computer hardware. This accumulation of knowledge may greatly exceed both the amount and quality of the expertise of a single human expert.

While an expert system can explicitly explain in detail the reasoning that led to a particular conclusion, a human expert may be unwilling to accept this all the time. This increases the confidence level of the decision making process by an expert system. The process of developing an expert system has an indirect benefit as well. Because the knowledge is explicitly represented in the knowledge base instead of being implicit in the human expert's mind, it can be examined for correctness, consistency and completeness. The knowledge may be adjusted and the quality of knowledge can be improved through this examining process.

The advantages mentioned for using the expert systems vs. real human experts can be found in many places. The following lists some of these advantages. (Golay M. W., C. W. Kang, 1998)

1. *With the help of an expert system, personnel with little expertise can solve problems that require expert knowledge. This is also an important factor in cases where human experts are in short supply. In addition, the number of people with access to the knowledge increases.*
2. *The knowledge of several human experts can be combined, which gives rise to a more reliable expert systems, a system that is based upon the collective wisdom of several experts, rather than on the experience of a single expert.*
3. *Expert systems can answer questions and solve problems much faster than the human expert. Thus, expert systems are invaluable in cases where time is one major critical factor.*
4. *In some cases complexities of the problem prevents the human expert from reaching a solution. In other cases the solutions obtained by human experts are unreliable. Due to the capabilities of computers processing a huge number of complex operations in a quick and accurate way, expert systems can provide both fast and reliable answers in situations where the human experts cannot.*
5. *Expert systems can be used to perform monotonous operations and others that are boring or uncomfortable to humans. Indeed, expert systems (e.g., an unmanned*

airplane or a spaceship) may be the only viable option in a situation where the task to be performed may jeopardize a human life.

6. *Substantial savings in cost can be achieved from using the expert systems.*

Because of advantages such as these, the number of expert system applications has grown very rapidly in many areas such as business, medicine, science, education and engineering during the last decade. Figure 1-2 shows the expert system application areas and the distributions in each group. Around 2,500 expert systems were examined and grouped according to several criteria such as fields of applications, task performed, etc. (Durkin J., NY, 1994)

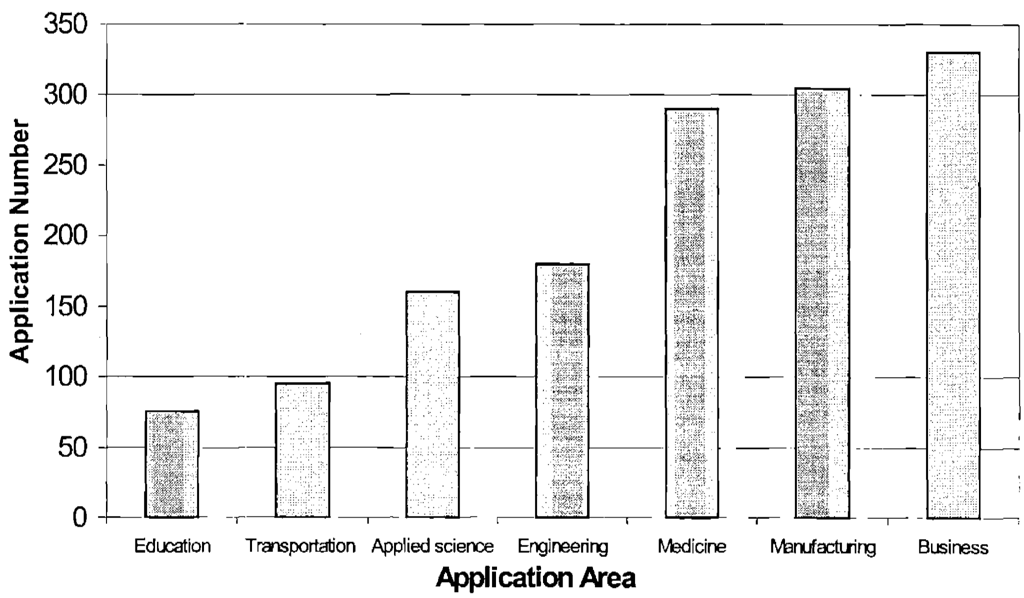


Figure 1-2. Distribution of application of expert system (Durkin J., NY, 1994)

However, expert systems still have some limitations. It takes a lot of time to build the expert system with many hours spent in testing and debugging. Also, expert systems lack the more subtle things that constitute human intelligence such as intuition. Sometimes decisions are made through intuition. Since there is no defined rule for how intuition works, it can't be programmed into computers. Also, expert systems have no ability to learn from its mistakes. If a human expert came to an incorrect conclusion, he/she would be able to understand and learn from the mistake in order to avoid making the same or similar mistakes in the future. An expert system, however, can't learn from its mistakes and would not be able to avoid making the same mistake in the future. Once an expert system is found to have an error, the only way to fix that error is to have it reprogrammed. In addition, it is said that every expert system has common limitations as follows, regardless of the choice of expert system building methodologies.

1. The size of the expert system (computation algorithm) grows very rapidly with the complexity of problem to solve. Sometimes, it grows beyond the practical limit.
2. Computation time increases very rapidly with the size of algorithm in the expert system.

Even though there is no specific answer to solve the limitations above, there are some ways to build up the expert systems in the problem domain with those limitations.

1. Find a better algorithm – ideal solution, but sometimes this is impossible.
2. Settle for an approximate solution – raise a trade-off condition between money, computation time and good precision of solution.
3. Simplify the problem – obtain an insight of the problem.

1.3 Three approaches in the expert systems

Three approaches generally used for building the expert systems are examined in this section: 1) neural networks, 2) fuzzy-rules, and 3) Bayesian Belief Networks (BBN). As mentioned in Section 1.2, the expert systems are applied to almost every area in society. Among these application cases, some typical examples of each approach are selected and illustrated in this section. Through these illustrations, identification of the strengths and weaknesses of each approach is sought as well as identification of which approach is proper to the problem domain in this work based upon those strengths and weaknesses.

1.3.1 Neural networks

Although there are also biological neural networks, when referring to a neural network for the expert system design it is assumed that an Artificial Neural Network (ANN) meant. The most basic components of neural networks are modeled after the structure of the human brain. Some neural network structures are not closely related to the brain and some do not have a biological counterpart in the brain. However, neural networks have a strong similarity to the biological brain and therefore a great deal of the terminology is borrowed from neuroscience. The ANN has many different names, such as 1) connectionism, 2) parallel distributed processing, 3) neuro-computing, 4) natural intelligence systems, or 5) machine learning algorithm. It is an attempt to simulate the human brain structure and functions within specialized hardware or sophisticated software with multiple layers of simple processing elements called neurons and their connections, as seen in Figure 1-3. Each neuron is linked to certain of its neighbors with varying coefficient of connectivity that represents the strengths of these connections. The ANN is sometimes called machine learning algorithms because changing of its connection weights (i.e., training) causes the networks to learn the solution to a problem. The strength of the connection between neurons is stored as a weight-value for the specific connection. The ANN learns new knowledge by adjusting these connections.

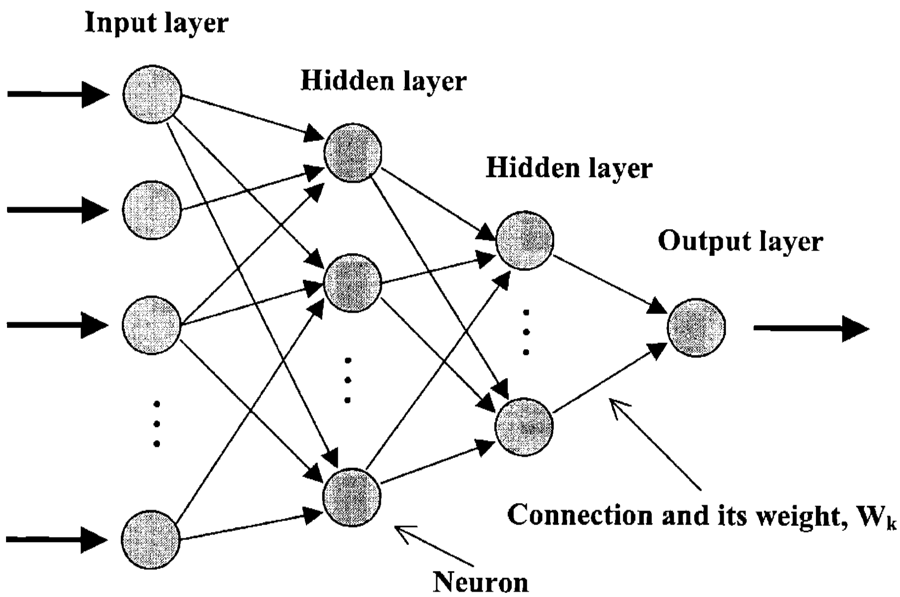


Figure 1-3. Simple neural networks

Environmental engineering application

Booty and et al. developed the chemical decision support system and they spent the majority of the effort on understanding the structure of a problem and collection of proper data. (Booty W. G., D. C. L. Lam, I. W. S. Wong, P. Siconolfi, 2001) In this example, the authors discussed that the ANN approach was selected because it does not require complete understanding of the relationships among variables. However, a large number of sample sets is required to train the ANN, which is not an easy process.

Biomedical application

Morimoto T. and Y. Hashimoto applied an ANN approach to a hierarchical intelligent control system for optimizing an entire plant-production process. Here, the ANN was used to identify plant responses to environmental factors and to search for optimal environmental setpoints through simulation of identified models. From the authors' discussion, the ANN approach showed the capability to identify unknown complex systems with its own leaning ability but the analysis of the trained ANN was very difficult. (Morimoto T., Y. Hashimoto, 2000) Also, like in the previous environmental engineering application case, obtaining a larger number of proper sample data sets to train was a difficult and time-consuming process.

Medical application

In the medical application example by Zhou and et al., the ANN was used in the research of an automatic pathological diagnosis procedure, named NED (Neural Ensemble-based Detection). Zhou and et al. discussed that an ANN approach was the key to improve the performance of the whole system since it does not require a complete understanding of the problem structure and the relationships among variables. (Zhou Zhi-Hua, Yuan Jiang, Yu-Bin Yang, Shi-Fu Chen, 2002)

Material science and engineering application

A hybrid intelligent system was developed for the design of new hydro-carbon structure, based upon the ANN approach. (Sohrabi. M. R, A. R. Mirzai, A. Massoumi, 2000) Sohrabi and et al. mentioned that the key reason for selecting the ANN approach in this application was that the ANN is capable of modeling the inter-relationships between inputs and outputs of a system through the process of learning, even without complete understanding of the problem structure. However, this capability is not true with the other approaches that are commonly used in developing the expert systems.

Construction project management application

In the construction project management application example, the key project management factors associated with achieving successful project performance were identified using a predictive modeling approach with the ANN. (Chua D. K. H., P. K. Loh, Y. C. Kog, E. J. Jaselskis, 1997) In the case of complex construction industry, the functional relationships between the management inputs and the project outcomes usually cannot be clearly defined. Chua and et al. showed that the ANN approach could provide a means where these relationships can be learned from specific cases of the real-world experience in this example. However, more data on the key management factors should be collected and presented to the model for training, in order to enhance the model performance and the knowledge domain of the ANN.

1.3.2 Fuzzy-rules

The rule-based approach to the development of expert systems is based upon the principles of classical logic and is well suitable for use in the problems involving exact relationships or at least relationships having very strong dependencies. In these systems, the knowledge is represented by a set of rules (also known as production rules), generally elicited from real human experts. These rules reflect the essential relationships among factors in the specific problem domain or rather they represent the ways to reason from cause to conclusion in the domain. (Golay M. W., C. W. Kang, 1998)

A rule is an expression having the form of,

***If** A **then** B*

where *A* is an assertion and *B* can be either an action or another assertion. For example, the following three rules are part of a large set of rules for representing the water pump failure mode (cause) and symptoms (effects). (Jensen F. V., Denmark)

1) ***If** pump failure **then** the pressure is low*
2) ***If** pump failure **then** check the oil gauge level*
3) ***If** power failure **then** pump failure*

When specific information representing current domain knowledge (i.e., current evidence) comes into an expert system, the rules are used to draw conclusions and to advise a proper action among alternatives from a knowledge base. The process is called '*inference*', which takes place as a kind of chain reaction. According to the rules above, if there is a power failure, Rule 3 can state that there is a pump failure and rule 1 can, then means that the pump pressure might be low. Rule 2 can advise to check the oil gauge level. These rules can also be used in the opposite direction. Suppose that the pressure is low, and then Rule 1 states that it can be due to a pump failure, while Rule 3 states a pump failure can be caused by a power failure. At same time, Rule 2 can be used to recommend checking the oil gauge level.

The conventional rule-based expert systems usually do not deal with uncertainties since objects and rules are treated in deterministic ways (i.e., Boolean or binary ways – yes or no). In order to overcome this weakness, fuzzy logic is incorporated into traditional rule-based systems. Fuzzy logic is a superset of conventional (Boolean) logic that has been extended to handle the concept of partial truth (i.e., truth-value between 'completely true' and 'completely false'). It was introduced in the 1960s as a mean to model the uncertainty of natural language. With the help of fuzzy logic, a fuzzy-rule based expert system was developed. It is an expert system that uses a collection of fuzzy membership functions as seen in Figure 1-4 and rules, elicited from human experts, to reason into the conclusion. However, it should be noted that the inference mechanisms of the fuzzy-rule base do have some weaknesses: 1) weak theoretical foundation, 2) inconsistency, and 3) sometimes oversimplification of the real world. Therefore the fuzzy-rule approach can be used under limited conditions. These weaknesses will be discussed again in Section 1.3.4.

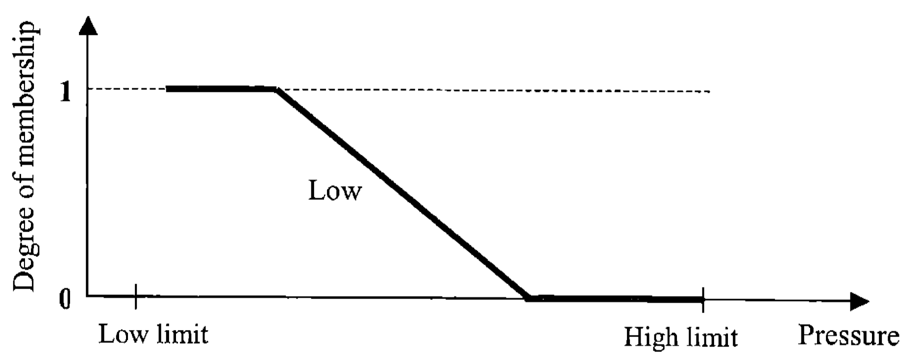


Figure 1-4. Example of fuzzy membership function

Civil engineering application

The expert system for deciding whether to drill underbalanced or overbalanced was developed using the fuzzy-rule approach by Garrouch and et al. The authors expressed that the main reason for selecting the fuzzy-rule approach was the ability of fuzzy logic for handling cases that lend themselves to partial truth. (Garrouch Ali. A, Haitharn M. S. Lababidi, 2001) This approach makes the expert system a powerful tool for analyzing ambiguous scenarios. As a consequence, this expert system enables the user to decide on an infinite number of cases that may be ambiguous for real human experts.

Medical chemistry application

This application example illustrates a novel technique based upon the fuzzy-rule approach that allows both the prediction of pharmacological activity and the development of new compounds. (Marco Russo, N. A. Santagati, Edoardo Lo Pinto, 1998) Based upon the author's discussion, the fuzzy-rule approach offers advantages in treating the linguistic nature of pharmacological activity as compared with classical Boolean approach.

Geography application

Current soil maps in geographic analysis and especially in the Geographic Information System (GIS), Polygon soil maps, have some major problems due to Boolean (or binary) logic and cartographic techniques. Soil in a landscape is a continuum and the discretization of such a continuum into distinct spatial and categorical groups results in a significant loss of information. (Zhu A-Xing, Lawrence E. Band, Barry Dutton and Thomas J. Nimlos, 1996) In order to overcome these weaknesses, the fuzzy-rule based expert system combining with GIS was developed to infer soil series from environmental conditions by Zhu and et al. The fuzzy logic can express more exactly the ambiguity of a map's boundary and the continuous characteristics of soil.

Data mining application

Traditionally, data mining operation can be readily extended to a symbolic form of data. The symbolic data can be taken from the form of natural language. (Stuart H. Rubin, 1998) Therefore, in this application example, the expert system based upon fuzzy-rule approach was developed in order to reflect the ambiguity of natural language in decision-making processes by Stuart.

Chemical plant maintenance application

Fonseca and et al. developed the fuzzy-rule based expert system, combined with the Reliability Centered Maintenance (RCM) method, in order to assess and evaluate all relevant equipment failure modes and their corresponding effects, before the actual process is set up for production, in large scale chemical industry plants. (Fonseca D. J., G. M. Knapp, 2000) In this application example, fuzzy logic was used to represent the situation whether or not a particular failure mode of interest occurs and, if it occurs, then how much the risk would be.

1.3.3 Bayesian Belief Networks

The Bayesian Belief Network (BBN) is also called Bayes Nets, Causal Probabilistic Network (CPN) or simply Belief Network (BN). A BBN consists of a set of nodes and a set of directed acyclic[1] (i.e., non-cyclic) arrows between nodes reflecting the domain of interest. Within the BBN, the nodes represent random variables in the domain and the arrows represent the causal relationships between these probabilistic state variables. While the relationships among variables in a problem domain are expressed with a set of fuzzy membership functions and rules in the fuzzy-rule based system as in Section 1.3.2,

[1] A directed acyclic means no directed cycle. That is, in a directed acycle, travel from a node and return to that same node along a nontrivial directed path cannot be accomplished.

a set of conditional probability values represents the strength of causal relationships between dependent variables, as shown in Figure 1-5.

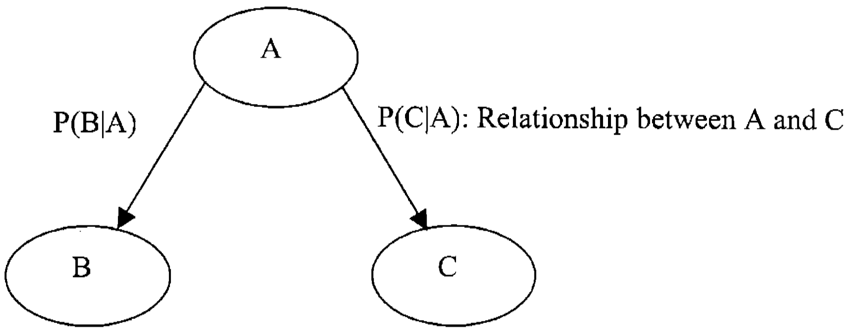


Figure 1-5. Simple Bayesian Belief Network

A BBN relies upon the Bayes' theorem for updating and an influence diagram for decision making. In the BBN, the probability of an event as a subjective degree of belief in its occurrence can be estimated, and also provides a measure of uncertainty that takes into account all available relevant knowledge and information. This uncertainty can arise from the imperfect understanding of the domain, incomplete knowledge of the state of the domain at the time when a given task is to be performed and randomness in the mechanisms governing the behavior of the domain.

A Bayesian Influence Diagram (BID) is a part of the BBN augmented with decision (action) and utility (cost and benefit) functions. Influence diagrams have been used successfully in uncertain complex decision-making problems through simple topological symbols and links between them, and cost & benefit analysis methodology.

Fossil power plant application

The expert systems in large-scale industry application, such as fossil power plants, should require the ability to manage uncertainty and time. In this application example, an expert system to assist an operator of fossil power plants was developed by Arroyo-Figueroa and et al. The developed system is a real-time knowledge based system to act as an operational and diagnostic aid to the operators of power plants. The authors discussed that the BBN approach provides a robust and sound formalism to represent and handle uncertainty in intelligent systems in a way that is consistent with the axioms of probability theory. Also a BBN has a number of important properties such as efficient and complete inference algorithms and several machine learning and explanation methodologies. Consequently, a BBN can be used to recognize events and state variables with respect to current plant conditions (i.e., current evidence) and predict the future propagation of disturbances. However, knowledge acquisition and estimating conditional probability are difficult process during developing a BBN model. (Arroyo-Figueroa G., Y. Alvarez, L. E. Sucar, 2000)

Veterinary medicine application

McKendrick and et al. developed the BBN-based expert system to quantify expert opinion with a view to estimating the likelihood of various diseases in the presence and absence of certain signs. During the developing process, knowledge acquisition among variables and estimation of conditional probability were not easy processes. However, based upon the author's discussion, if knowledge acquisition and estimation of conditional probability are correctly representing the human experts idea, then it is possible to deal with uncertain situations and to update the knowledge base in the BBN using current evidence accurately. (McKendrick I. J., G. Gettinby, Y. Gu, S. W. J. Reid, C. W. Revie, 2000)

Medical application

Güvenir and et al. developed an expert system called DES (Diagnosis of Erythemato-Squamous) that presents a dermatologist or a student with the diagnostic results of three classification algorithms. The BBN approach was used to develop a classifier called the Bayesian classifier, which is an algorithm that approaches the classification problem using conditional probabilities of the features. The system is consistently updated using evidence based upon the BBN approach, which is a main advantage of this classifier, based upon the discussion in the paper. (Güvenir H. A., N. Emeksiz, 2000)

Chemical plant diagnosis application

In this application example, a qualitative model-based fault diagnosis expert system based on the Possible Cause and Effect Graph (PCEG) methodology was developed by Leung and Jose. During execution of the system, the knowledge captured in a static casual network may be insufficient to describe the temporal domain. Leung and Jose mentioned that, under these circumstances, the BBN approach provides updating capability based upon captured current knowledge, and then the system can supply the latest process information to the users. (Leung. David, Jose Romagnoli, 2000)

Nuclear power plant diagnosis application

In this application example, an expert system based upon a BBN approach for improved operational availability in complex nuclear power plant systems was developed by Kang. The author discussed that the reason for selecting the BBN approach was that the artificial neural networks and the traditional rule-based approaches cannot properly model the inherent large uncertainties and complexities of the relationships involved in the diagnosis of actual complex engineering systems, such as nuclear power plant systems. (Kang C. W., M. W. Golay, 1999) The developed expert system can provide reasonable numerical evaluations about the uncertain failure mode-state and then, advise proper operational action from alternatives for that specific situation.

1.3.4 Strengths and weaknesses of each approach

In this section, strengths and weaknesses of three approaches are discussed based upon the generally known facts and survey results in Section 1.3.3.

Artificial neural networks approach

As discussed in Section 1.3.1, the main feature of an artificial neural networks based expert system is that of multiple layers of simple processing elements, called neurons, connections and their weights that can be trained automatically with a sample data set to behave in the right way. Artificial neural networks can automatically adjust their weight to optimize their behavior as pattern recognizers, decision makers, system controllers, predictors, etc. Therefore, the most important strength of artificial neural networks can be their adaptivity and hence, it does not require a complete understanding of complex relationships among variables in the application domain. Adaptivity allows the artificial neural network to perform well even when the environment or the system being controlled varies over time. Many control problems can benefit from continuous nonlinear modeling and adaptation.

A disadvantage is that it requires a large number of sample data sets to train the artificial neural networks in the right way and this learning process is relatively slow. Since there is no complete understanding of leaning process and trained artificial neural networks with training data sets, analysis of results given by artificial neural networks is very difficult. Therefore, the artificial neural networks cannot be a proper approach in cases when the complete understanding of a problem domain and the path to final results are needed.

Fuzzy –rule approach

In the fuzzy-rule based expert systems, the relationships between variables in domain are represented by a set of pre-specified rules. The entire structure of the modeling is not visible to the developer or user because the corresponding knowledge is reflected as the text format in the form of the ***If-Then*** type rather than object-oriented graphics. Therefore it is very difficult to obtain an overall picture of the whole system from a set of rules. Moreover, great effort is needed to maintain the completeness and consistency of the entire inference algorithm since each rule is developed in an independent manner during all stages of expert system development and the complex problem representation in rule-based expert system requires a great number of rules. Also when changes must be made, that large number of rules is very cumbersome to treat properly.

For the uncertainty treatment in the fuzzy-rule based expert systems, uncertainty management can be performed using a set of fuzzy membership functions but these theoretical mechanisms do not have a sound theoretical foundation and may even be inherently inconsistent. Also such theories simplify the real world and are employed safely only under very limited conditions. (Golay M. W., C. W. Kang, 1998) In short, a fuzzy-rule based expert system does not have efficient uncertainty management capabilities. So decision making in the fuzzy-rule based expert systems is either realized qualitatively, which is not satisfactory in many cases, or complemented by some procedural subroutines that perform mathematical calculations, thereby introducing new complexity into the systems. Artificial decision making using the fuzzy-rule based system typically involves greater effort than with the BBN-based system.

In modifying the fuzzy-rule based expert systems, many associated rules usually have to be searched for in order to reflect any changes in the knowledge base. Sometimes their implicit structures make the selection of associated rules more difficult. Moreover, the meaning of an uncertainty factor is artificial and difficult to explain as a measure of change in belief. Sometimes, in order to correct the expert system's logic, extra rules have to be introduced to ensure that other rules are triggered in the right order. Thus, rule-based systems generally require rigorous testing and validation due to the problems mentioned above. Domain experts find them very difficult to follow during debugging, as the new rule processing does not always flow logically.

Bayesian Belief Networks approach

In the BBN-based expert systems, the graphical knowledge representation is used. The objects are represented as nodes and their relationships as links between the nodes in domain. The BBN makes the domain structure explicit and utilizes the topology of the graph in the control of the inference. This type of object-oriented programming is the result of an evolution of programming, where newly developed tools make some programming tasks easier and more natural. It is much easier to maintain the completeness and consistency of the modeling system because the entire structure of the model is readily understood. The graphical representation and the conditional probability values used make BBN-based expert systems especially desirable for use in the complex problem solving. Use of the Bayes' theory combined with either causal or information flow networks reduces the amount of conditional dependence assumptions used and the number of conditional probability values that need to be specified. Furthermore, the BBN is not limited to use of binary logic in rule-based approach, as a BBN node can be divided in as many states as needed.

In the BBN-based expert systems, the BBN gives the probability values of an event as a measure of the uncertainty of its occurrence. The fact that the BBN is based upon probability theory can permit us to use pre-existing knowledge and statistics to learn the prior and conditional probability values of the network elements. The BBN representation overcomes many of the limitations of the uncertainty factor model and provides a promising approach to the practical construction of expert systems in an inherently uncertain world. The BIDs have been combined successfully with the probability values of event occurrences in complex decision-making problems by graphically representing the domain through simple topological symbols and links between them. Decision nodes in the BID represent points at which choices have to be made between well-defined alternatives and links directed to a decision node depicting information available at the time of making the decision. The procedure of decision making can be modeled explicitly by taking into account utilities (i.e., costs and benefits) in the utility node associated with particular combinations of management measures and the true state of the system. The action alternative with the highest expected utility value is suggested for use in the inference algorithm in the BBN-based expert systems. (Golay M. W., C. W. Kang, 1998)

For the modification of expert systems, the software editor module provides facilities for editing the network of interest (i.e., creating or deleting nodes and conditional probability tables). Explicit models are much easier to modify because they represent the entire structure of the system represented in a natural, transparent manner. Thus, such a model is much easier to maintain and verify, and hence has a larger life span than that of rule-based expert systems.

The BBN approach is appropriate to store expertise from different topics in same problem domain or even from other disciplines. Once an investment has been made in designing the software, further applications can be easily developed when the required conditional probabilities are available. Information about the specific system under study is coded within the conditional probability parameters rather than within the logical framework of the expert system. One of weaknesses of the BBN method is that the logical processes of the resulting expert system will not necessarily be very clear to the user because information is processed through a mathematical structure. This problem is exacerbated by the fact that the BBN simultaneously processes all available information after each interaction with the user. In addition, obtaining and adjusting the conditional probability sets for describing the strength of dependencies among variables are very difficult and time-consuming work in the BBN approach.

Selection of the Bayesian belief network approach

There are various sources of uncertainty in most practical applications, especially in the area under this work, project management. Observations may be uncertain, information obtained may be incomplete and the relationships in the domain may be of a non-deterministic (i.e., stochastic or probabilistic) type. Thus there is a need for expert systems that can deal with uncertain situations in a systematic way. In addition, the complete explanation to results or advice given by expert systems is required in order to enhance understanding the nature and the dynamics of the project management area. Among three alternatives, the BBN approach can be said to be superior to the fuzzy-rule approach in its ability to represent the complex problems in a domain of inherent uncertainty and to provide project managers better understanding of project management than the artificial neural network approach. Therefore, the BBN approach is selected as a modeling language in this work.

1.4 Motivation of work

The management of the project (usually the Project Manager (PM)) is expected to coordinate and integrate all activities needed to accomplish the project's goal. In particular, the project managers should be responsible for: 1) identify the problems in the project at an early stage, and 2) make timely and proper decisions to correct the identified problems. In the situation of difficult decision making, it would be a great source of comport if one could predict with reasonable certainty how much the project performances of time and cost goals would be achieved at a time in the future after taking one of the action alternatives. In a few cases, for example, very routine and repeated construction projects, a reasonably accurate prediction could be estimated, but, in most cases, this was believed to be nearly impossible until very recently. Nowadays, however, computer programs can predict the future and advise the better choice to some reasonable degree, with the help of accumulation of knowledge on project management dynamics and of development in computer technology. Therefore, there is a growing need for this kind of computerized system (i.e., expert system or advisory system) for project management that can help the project managers understand the status, predict the future performances of project and optimize decisions among alternatives.

The main purpose of advisory system development in this work is to help the project managers to enhance the understanding current situations and hence to optimize decisions, especially in hard decision-making situations and during the entire project lifetime as well. In order to achieve this purpose, the advisory system should include three main functions. The first is to predict future project performance state probability distributions given a set of evidence reflecting current project performance. It is necessary to evaluate whether a future project performance state will be in good shape without any intervening action. If a bad project performance will be predicted in the near future, then the project manager should take proper action promptly to correct problems. The second is to give the expected optimal action among alternatives to the project manager under the given circumstances to maximize the net benefits or preferences. This would be the main function of the proposed advisory system. The last function is to predict both post-action and project-completion performance state probability distributions if the project manager takes an action from the alternatives.

Further, the advisory system will enhance control in time, costs, quality and reliability of the projects. Especially in the nuclear power plants construction project, the project managers will be able to manage their work more effectively and efficiently with a well-developed advisory system and other available technologies. Hence, one of the major elements of electricity cost, the capital cost of nuclear power plants, will be reduced. As a result, the nuclear power plants will have more competitive power in the electricity market.

1.5 Linkage with currently used computer programs

In recent years, the need of computerized systems for more efficient scheduling and monitoring is growing rapidly in project management for every area of industry, especially in large-scale projects such as in the construction industry. In order to meet this purpose, a lot of effort has been made in design and development of such computerized management systems. As a result of this effort, several computerized programs, such as Primavera Enterprise, Microsoft Project, CA-Super Project, IMSI Turbo Project and Artemis were developed and are used currently in the real project management world. (http://web.mit.edu/pm/tools.html) The advantages of computerized programs for project management are summarized below. (http://www.primavera.com) However, they do not have explicit and definite capabilities for handling uncertainties, in spite of the uncertainties found in project management problems because these programs employ a deterministic approach. Also, they don't have functions for decision making like the advisory system in this thesis does. It should be noted that the main purposes of the computer programs above are project scheduling and performance monitoring. Hence, they can help project managers in the management decision-making process by providing proper information.

Advantages:

- *Achieve the project schedule and budget objectives,*
- *Increase speed and efficiency of project execution,*
- *Monitor project portfolio performance,*
- *Standardize processes for uniform project control,*
- *Document project changes, issues and details,*
- *Communicate effectively with various involved personnel,*
- *Keep project moving through collaborations,*
- *Respond faster to potential changes,*
- *Manage project's risks effectively,*
- *Simplify progress payments and negotiations,*
- *Easy access to project's specifications, plans and due date.*

The users should enter proper input information into the computerized scheduling systems as illustrated in Figure 1-6, such as: 1) work activity I.Ds., 2) work activity names, 3) time duration of each work activity (i.e., start and end date) and 4) required resources for each work activity (i.e., man-hour, budget, materials, etc.). Based upon the entered information, the computer systems can optimize the work schedule using several approaches. The most common approach to project scheduling is the use of network techniques such as PERT (Program Evaluation and Review Technique) and CPM (Critical Path Method). (Meredith Jack R., S. J. Mantel Jr., 2000) The results are provided in many forms and the graphical form is one of the typical outputs from these computer systems. Figure 1-7 shows one typical graphical output for an optimized work schedule, a Gantt chart that is the standard format for displaying a schedule graphically. It consists of a horizontal bar chart with time as the horizontal axis and either resources, jobs, or orders as the vertical axis.

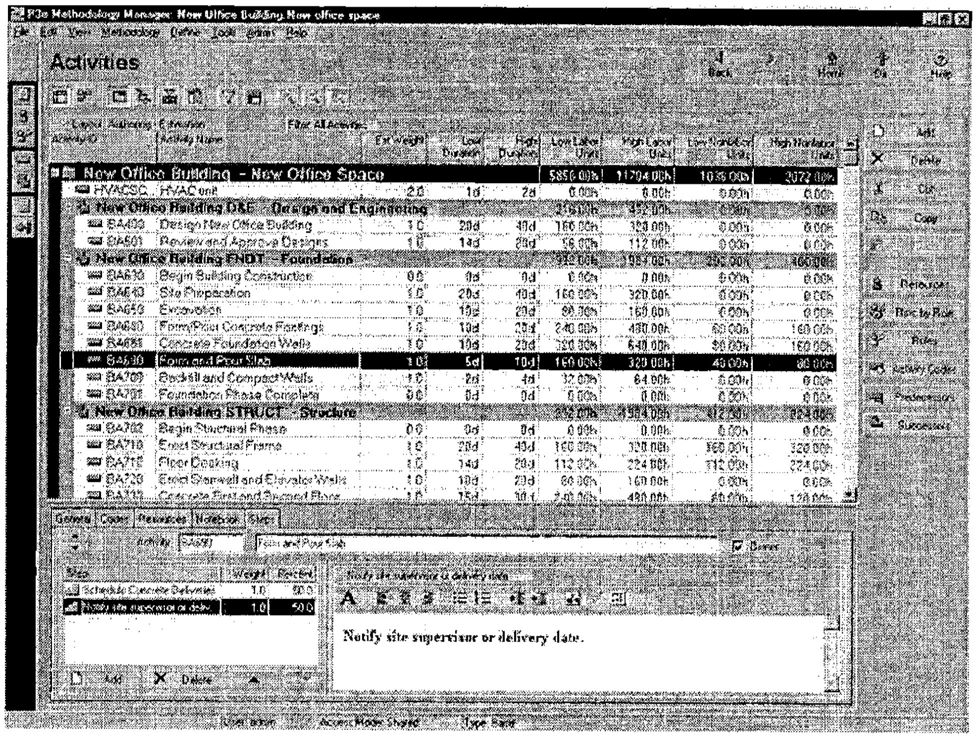


Figure 1-6. Input to computerized scheduling programs (http://www.primavera.com)

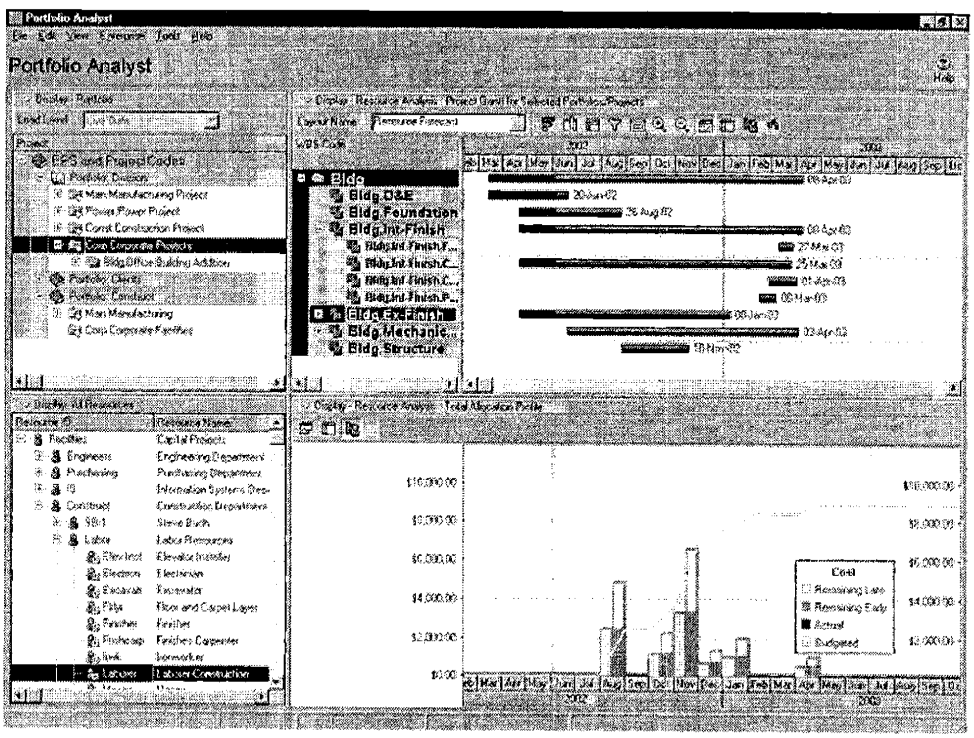


Figure 1-7. Output of computerized scheduling programs (http://www.primavera.com)

Among the programs listed above, Primavera Enterprise and Microsoft Project are the most popular ones to project managers in the real world of construction projects, which are of interest in this thesis. Therefore, this thesis focuses on these two programs since they are most widely used ones in the real world. While Primavera Enterprise is good for large-scale projects, Microsoft Project is generally used for small-scale projects. The definition of large or small is not clear but the following definitions for term "large" are used in the real world: 1) over 20 decision points during entire project lifetime, 2) over 50 work activities (smaller size of work than work packages – generally a single work package has several work activities) and 3) over $ 0.5 million budget. Primavera Enterprise can track project performances nearly continuously (i.e., generally on daily or hourly basis) but Microsoft Project tracks performances on a monthly basis or by checking up on the project milestones. They both can optimize the project schedule and monitor the current and past project performances.

As discussed above, the computer programs for scheduling and monitoring can only help the project manager by providing information for decision making. They cannot make decisions or give advice on management decisions like the advisory system developed in this work. In other words, while the computer programs above are a source of information for the decision-making process and need the project managers to make decisions, the advisory system in this thesis simulates the project managers' decision-making process itself and needs information for decision-making process. Therefore, the advisory system in this work can be deployed as the next step after the computer programs for scheduling and monitoring. Through discussions with domain experts, it is concluded that the linkage between the computer programs for scheduling and monitoring and the BBN advisory system would have a structure as shown in Figure 1-8. The computer programs for scheduling and monitoring provide the following information to the BBN advisory system:

1. Source of input signal (current project status) – The BBN advisory system requires the index values for seven important input factors about the current project

performance status as evidence inputs. Primavera Enterprise and Microsoft Project monitors all variables for current project performance status. Hence, the index values for seven important input factors can be computed, based upon the monitored variables. These index values can be transferred to the BBN advisory system and used as current evidence inputs. For example, suppose that the monitoring computer system indicates the current project time performances (i.e., *ATWP* and *STWP*) as follows. Then, the TPI (Time Performance Index – one of seven important input indices) calculation is as shown in equation (1-1).

$$TPI = \frac{STWP}{ATWP} = \frac{180}{200} = 0.9 \qquad (1\text{-}1)$$

where

ATWP: Actual Time of Work Performed = 200 days

STWP : Scheduled Time of Work Performed = 180 days

2. Data pool for updating expertise (i.e., conditional probability distributions used for reasoning in BBN models). – The conditional probability distributions in the current BBN advisory system have been acquired through discussions and surveys with domain experts, since there is not enough real case information for computing the conditional probability values. However, it is possible to update these probability values continuously when Primavera Enterprise and Microsoft Project store the real case information and provide it to the BBN advisory system. As a result, the BBN advisory system can always have the most updated expertise in the project management area.

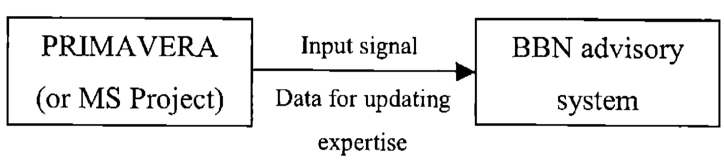


Figure 1-8. Linkage between computer programs for scheduling and BBN advisory system

CHAPTER 2.
BAYESIAN BELIEF NETWORK-BASED EXPERT SYSTEMS

2.1 Bayesian updating

The Bayes' theorem in equation (2-1) is the key point of updating the probability of being true of a certain hypothesis H_i.

$$P(H_i \mid E) = \frac{P(E \mid H_i)P(H_i)}{\sum_i P(E \mid H_i)P(H_i)} \quad . \tag{2-1}$$

All probabilities here represent the degree of belief in those events (i.e., hypotheses). After new evidence, E, is received reflecting current our knowledge, which reinforces or weakens that hypothesis, the prior degree of belief, $P(H_i)$, can be formally updated into the posterior belief $P(H_i|E)$ according to Bayes' theorem as in equation (2-1). Bayes' theorem is particularly useful in the situations where probability values are more easily obtained in one inferential direction than another, thus providing the flexibility to reason in either the causal or the information flow direction. Equation (2-1) provides a convenient way of updating belief in a proposition in light of new evidence.

In the BBN, the probability distribution of the states of any dependent node (a node where the true state is unknown, this type node usually is called as child node) at a particular domain within the network is defined in terms of the conditional probability values, as shown in Tables 2-1and 2-2, and links between the independent node states (those where the nodal state is know with certainty/evidence, usually these type nodes are called parent nodes) and the dependent node states as shown Figure 2-1.

Table 2-1. Conditional probability table P(B|A) for node B the BBN in Figure 2-1

B \ A	a_1	…	a_i
b_1	x_1	…	y_1
b_2	x_2	…	y_2
…	…	…	…
b_j	x_j	…	y_j

where $1=\sum_{n=1}^{j} x_n = \sum_{n=1}^{j} y_n$

Table 2-2. Conditional probability table P(C|A) for node C the BBN in Figure 2-1

C \ A	a_1	…	a_i
c_1	m_1	…	t_1
c_2	m_2	…	t_2
…	…	…	…
c_k	m_k	…	t_k

where $1=\sum_{n=1}^{k} m_n = \sum_{n=1}^{k} t_n$

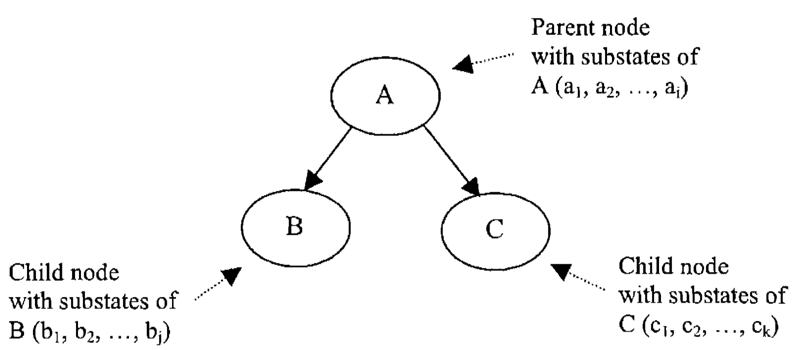


Figure 2-1. A simple BBN

Given a fully specified BBN, the joint probability distribution of the variables can be constructed using following conditional probability relationships.

$$P(B \mid A) = \frac{P(A \cap B)}{P(A)},\ P(C \mid A) = \frac{P(A \cap C)}{P(A)} \quad . \tag{2-2}$$

If evidence from node B and C is provided, the posterior probability distribution of the states of node A is computed using the prior probability distribution of node A and conditional probability values. If evidence from node A is provided, the posterior probability distributions of the states of nodes B and C are computed from conditional probability values without considering the prior probability distributions of node A because the prior probability distribution of node A is changed into evidence.

Let's suppose the following example and obtain the posterior probability distribution given evidence.

" *Police inspector Smith is impatiently awaiting the arrival of Mr. Holmes and Dr. Watson. But they are late and inspector Smith has another appointment. Looking out of the window he wonders whether the roads are icy. Both are notorious bad drivers, so if the roads are icy they may crash. At that time, his secretary enters and tells him that Dr. Watson has had a car accident. 'Watson? OK. It could be worse.... Icy roads! Then Holmes has most probably crashed too. I'll go to another appointment.' 'Icy roads?', the secretary replies, 'It is far from being that cold and furthermore all the roads are salted.' Inspector Smith relieved. "Bad luck for Watson. Let us give Holmes some more time."*'" (Jensen F. V., 2001)

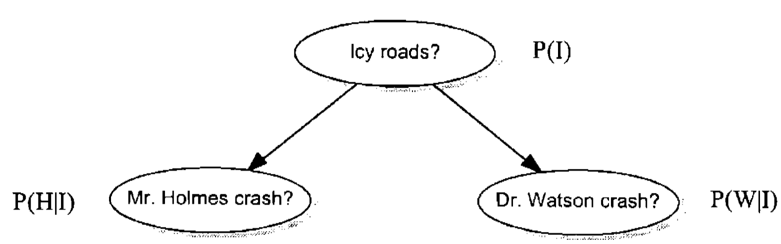


Figure 2-2. A BBN for icy roads example

Based upon this scenario, a simple BBN is developed as illustrated in Figure 2-2. For the quantitative estimation of the posterior probability distributions, three prior probability tables are needed; P(I), P(H|I) and P(W|I). Suppose the probability values are assigned using the knowledge up to now (prior belief – represents current knowledge but without any new evidence) as in Table 2-3.

Table 2-3. Probability tables for P(I), P(H|I) and P(W|I)

P(I)

	I = Yes	I = No
P(I)	0.7	0.3

P(H|I)

	I = Yes	I = No
H = Yes	0.8	0.1
H = No	0.2	0.9

P(W|I)

	I = Yes	I = No
W = Yes	0.8	0.1
W = No	0.2	0.9

Using the above prior probability distributions, the prior joint probability distributions can be calculated using the conditional probability relationships in equation (2-2). For example, the prior joint probability distribution for P(W∩I) and then P(W) are computed. The prior joint probability distributions for the other factors can be computed in same way.

$$P(W = yes \cap I = yes) = P(W = yes \mid I = yes)P(I = yes) = 0.8 \times 0.7 = 0.56$$

$$P(W = no \cap I = yes) = P(W = no \mid I = yes)P(I = yes) = 0.2 \times 0.7 = 0.14$$
$$P(W = yes \cap I = no) = P(W = yes \mid I = no)P(I = no) = 0.1 \times 0.3 = 0.03$$
$$P(W = no \cap I = no) = P(W = no \mid I = no)P(I = no) = 0.9 \times 0.3 = 0.27$$

$$P(W = yes) = P(W = yes \cap I = yes) + P(W = yes \cap I = no) = 0.56 + 0.03 = 0.59$$
$$P(W = no) = P(W = no \cap I = yes) + P(W = no \cap I = no) = 0.14 + 0.27 = 0.41. \qquad (2\text{-}3)$$

Now, we have new evidence that Dr. Watson has crashed, so this information can be used to update the probability distribution of our main interest of I (Icy road?) with Bayes' theorem in equation (2-1). Here, event *E* is "Dr. Watson has crashed: P(W = yes)".

$$P(I = yes \mid E) = \frac{P(E \mid I = yes)P(I = yes)}{P(E \mid I = yes)P(I = yes) + P(E \mid I = no)P(I = no)}$$
$$= \frac{0.8 \times 0.7}{0.8 \times 0.7 + 0.1 \times 0.3} = \frac{0.56}{0.59} = 0.95$$
$$P(I = no \mid E) = \frac{P(E \mid I = no)P(I = no)}{P(E \mid I = yes)P(I = yes) + P(E \mid I = no)P(I = no)}$$
$$= \frac{0.1 \times 0.3}{0.8 \times 0.7 + 0.1 \times 0.3} = \frac{0.03}{0.59} = 0.05. \qquad (2\text{-}4)$$

The probability distribution for "Mr. Holmes crash?" is updated using the posterior probability distribution of P(I)=P(I|E).

Equation (2-5)

$$P(H = yes \cap I = yes) = P(H = yes \mid I = yes)P(I = yes \mid E) = 0.8 \times 0.95 = 0.76$$
$$P(H = yes \cap I = no) = P(H = yes \mid I = no)P(I = no \mid E) = 0.1 \times 0.05 = 0.005$$
$$P(H = no \cap I = yes) = P(H = no \mid I = yes)P(I = yes \mid E) = 0.2 \times 0.95 = 0.19$$
$$P(H = no \cap I = no) = P(H = no \mid I = no)P(I = no \mid E) = 0.9 \times 0.05 = 0.045$$

$$P(H = yes) = P(H = yes \cap I = yes) + P(H = yes \cap I = no) = 0.76 + 0.005 = 0.765$$

$$P(H = no) = P(H = no \cap I = yes) + P(H = no \cap I = no) = 0.19 + 0.045 = 0.235 .$$

In summary, the prior probability distributions can be compared with the posterior probability distributions for all factors in this example given the evidence of "Dr. Watson has crashed: P(W = yes)" in Table 2-4. From this table, the larger probability values of the 'Yes' states of P(I) and P(H) in posterior distributions can be found because the new evidence of Dr. Watson's car accident was fed into the BBN. This result of increasing probability values can also be inferred qualitatively from a person's reasoning process, but not quantitatively. Therefore, the BBN can be said to simulate a person's reasoning process and also to have systematic quantitative ability.

Table 2-4. Prior vs. posterior probability distributions given evidence

	P(I)		P(H)		P(W)	
	Yes	No	Yes	No	Yes	No
Prior	0.7	0.3	0.59	0.41	0.59	0.41
Posterior	0.95	0.05	0.765	0.235	1	0

Figures 2-3 and 2-4 show a different form of the same results as in Table 2-4 using the HUGIN software for BBN modeling that is used for this study.

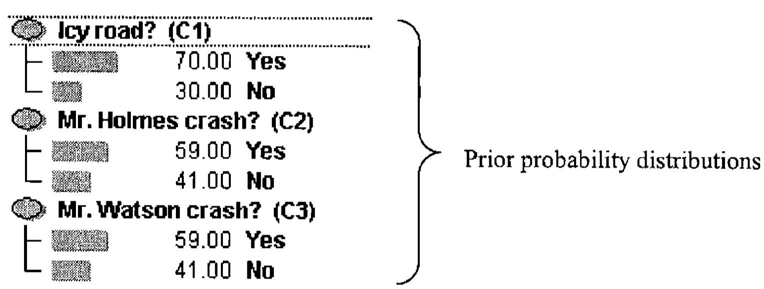


Figure 2-3. Prior probability distributions in HUGIN

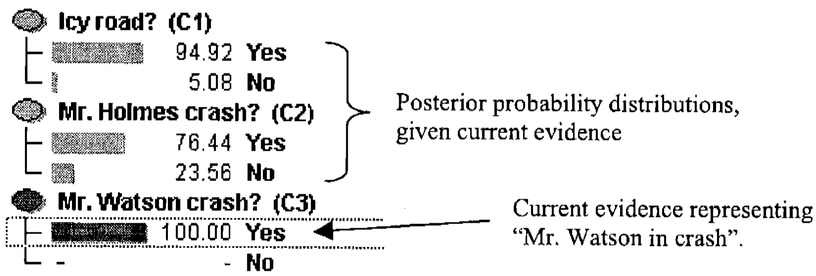


Figure 2-4. Posterior probability distributions in the HUGIN

2.2 Sensitivity to parameter

Definition of parameter

Let A be a binary states variable (i.e., A has two states, a_1, a_2) and let $pa(A)$ be a probability distribution of parent variable of A. Then $t = P(A = a_1 \mid pa(A))$ is a parameter, consequently $P(A = a_2 \mid pa(A)) = 1-t$, and they vary at the same time as t. If A has more than two states, it is assumed the "*Proportional scaling*"; the remaining probabilities are scaled with the same factor. For example, if A has n states and a_1 is a parameterized state, then the conditional probability distribution of A is assumed to be as follows.

$$P(A \mid pa(A)) = (t, (1-t)\alpha_2, (1-t)\alpha_3, \cdots, (1-t)\alpha_n). \qquad (2\text{-}6)$$

where

$$\sum_{i=2}^{n} \alpha_i = 1$$

It is also possible to deal with several parameters in the same distribution. If, for example, the first two states are parameterized, then the conditional probability distribution of A can be expressed as follows.

$$P(A \mid pa(A)) = (t, s, (1-t-s)\alpha_3, (1-t-s)\alpha_4, \cdots, (1-t-s)\alpha_n). \qquad (2\text{-}7)$$

where

$$\sum_{i=3}^{n} \alpha_i = 1$$

Sensitivity to parameters

Let's suppose the following example.

"In the morning when Mr. Holmes leaves his house he realizes that his grass (Holmes?) is wet. He wonders whether it has rained (Rain?) during the night or whether he has forgotten to turn off his sprinkler in his yard (Sprinkler?). He looks at the grass of his neighbors, Dr. Watson (Watson?) and Mrs. Gibbon (Gibbon?). Both lawns are dry and then he concludes that he must has forgotten to turn off his sprinkler." (Jensen F.V. 2001)

This example can be illustrated using qualitative knowledge as a BBN model as shown in Figure 2-5.

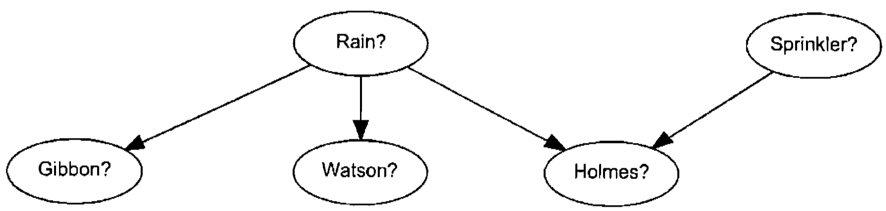


Figure 2-5. Wet grass BBN example

Suppose the following prior probability values are given to each factor as shown in Tables 2-5, 2-6, 2-7, 2-8 and 2-9.

Table 2-5. Probability values for Rain?

Rain?	Probability
Yes	0.1
No	0.9

Table 2-6. Probability values for Sprinkler?

Sprinkler?	Probability
Yes	0.1
No	0.9

Table 2-7. Conditional probability values for Gibbon?

Gibbon? \ Rain?	Yes	No
Yes	0.99	0.1
No	0.01	0.9

Table 2-8. Conditional probability values for Watson?

Watson? \ Rain?	Yes	No
Yes	0.99	0.1
No	0.01	0.9

Table 2-9. Conditional probability values for Holmes?

Sprinkler?	Yes		No	
Holmes? \ Rain?	Yes	No	Yes	No
Yes	1	0.9	0.99	0
No	0	0.1	0.01	1

The hypothesis in this example is that Mr. Holmes has forgotten to turn off his sprinkler h_s : = yes and the evidence can be as follows.

$e = \{e_H, e_G, e_W\}$

e_H : whether the grass of Mr. Holmes is dry

e_G : whether the grass of Mrs. Gibbon is dry

e_W : whether the grass of Dr. Watson is dry

Let *t* be a parameter in the 'No' state of factor Gibbon? in Figure 2-5, BBN model, then the Conditional Probability Table (CPT) for Gibbon? can be presented as in Table 2-10.

Table 2-10. Conditional probability values for Gibbon?

Rain? / Gibbon?	Yes	No
Yes	1-t	0.1
No	t	0.9

The item of interest is how posterior probability P ($h_s \mid e$) varies with the value of *t*. First, find how the prior probability of evidence P (*e*) varies with the value of *t*. Using the fundamental probability relationship in the Bayes' theorem, for example, the joint probabilities for $P(Rain? \cap Gibbon?)$ can be calculated as shown in Table 2-11.

Table 2-11. Joint probability ($P(Rain? \cap Gibbon?)$ values for Holmes?

Rain? / Gibbon?	Yes	No
Yes	0.1*(1-t)	0.9*0.1
No	0.1*t	0.9*0.9

When new information (i.e., new evidence e) is received, that the grass of Mrs. Gibbon is dry; evidence e_G, then the posterior probability distribution, $P(Rain? \cap e_G)$, can be expressed as follows.

Equation (2-8)
$P(Rain? \cap e_G) = (Rain = yes \cap Gibbon = dry, Rain = no \cap Gibbon = dry) = (0.1 * t, 0.81)$.

The prior probability value for evidence (i.e., the prior probability value of dry grass at Mrs. Gibbon's house) can be calculated as in the following expression.

$$P(e_G) = P(Gibbon = dry) = \sum_{Rain?} P(Rain? \cap e_G) = 0.1 * t + 0.81 . \qquad (2\text{-}9)$$

To find the probability for more complicated joint probabilities, e.g., $P(h_s \cap e_G)$ or $P(e_H \cap e_G)$, which cannot be calculated from the conditional probability values assigned in the tables above, access is needed to the joint probability $P(U) = P(A_1, \ldots, A_n)$ when $U = (A_1, \ldots, A_n)$ is a universe of variables. However, $P(U)$ grows exponentially with the number of variables and U does not need to be very large before the size of joint probability table becomes intractably large. Therefore, a more compact representation of $P(U)$ is required; a way of storing information from which $P(U)$ can be calculated if needed.

A BBN over U is such a representation. If the conditional independencies in the BBN hold for parent factors in U, then $P(U)$ can be calculated from the following theorem.

Let Bayesian network be over $U = (A_1, \ldots, A_n)$. *Then the joint probability distribution* $P(U)$ *is the product of all potentials specified in* $U = (A_1, \ldots, A_n)$. (F. V. Jensen, 2001)

$$P(U) = \prod_i P(A_i \mid pa(A_i)) . \qquad (2\text{-}10)$$

where $pa(A_i)$ *: parent set of* A_i

Proof)

If U consists of one variable, then the theorem is trivial. Assume the theorem above to be true for all Bayesian networks consisting of n-1 variables and let U be universe for n variables, $U = (A_1, \ldots, A_n)$. *Then the following expression is true from Baye's theorem.*

$$P(A_n \mid U \setminus \{A_n\}) = \frac{P(U)}{P(U \setminus \{A_n\})}. \qquad (2\text{-}11)$$

where, $U \setminus \{A_n\}$ *: the rest variables in U except* A_n

Here, the conditional probability $P(A_n \mid U \setminus \{A_n\})$ *can be expressed using the parent configuration of* A_n, $pa(A_n)$, *as in the following expression.*

$$P(A_n \mid U \setminus \{A_n\}) = P(A_n \mid pa(A_n)). \qquad (2\text{-}12)$$

Therefore, the following expression is valid for all n variables of U.

$$P(U) = P(A_n \mid U \setminus \{A_n\}) P(U \setminus \{A_n\}) = P(A_n \mid pa(A_n)) P(U \setminus \{A_n\}). \qquad (2\text{-}13)$$

The right-hand side of equation (2-13) represents the product of all specified probabilities in a conditional probability table assigned in the BBN and hence, holds equation (2-10) in the above theorem.

From the theorem above, the joint probability distribution for the universe in this example can be expressed using equation (2-14).

$$P(G \cap H \cap R \cap W \cap S) = P(G \mid R) P(H \mid R, S) P(R) P(W \mid R) P(S). \qquad (2\text{-}14)$$

Where, G=Gibbon?, H=Holmes?, R=Rain?, W=Watson?, S=Sprinkler?

Based upon the joint probability values from equation (2-14), all probability values of interest in this example can be calculated. For instance, suppose the evidence is that Mr. Holmes and Mrs. Gibbons grass states are dry, then the posterior probability of hypothesis, $P(h_s \mid e=\{e_H, e_G\}) = \frac{P(h_s \cap e_H \cap e_G)}{p(e_H \cap e_G)}$, can be computed in this wet grass example as in the following expressions.

$$P(h_s \cap e_H \cap e_G) = \sum_R \sum_W P(G = Yes \cap H = Yes \cap R \cap W \cap S = Yes) . \tag{2-15}$$

$$= P(G = Yes, H = Yes, R = Yes, W = Yes, S = Yes) + P(G = Yes, H = Yes, R = No, W = Yes, S = Yes)$$
$$+ P(G = Yes, H = Yes, R = No, W = Yes, S = Yes) + P(G = Yes, H = Yes, R = No, W = No, S = Yes)$$

$$P(e_H \cap e_G) = \sum_R \sum_W \sum_S P(G = Yes \cap H = Yes \cap R \cap W \cap S) . \tag{2-16}$$

For example, one part of equation (2-15) can obtain the conditional probability values in Tables 2-5, 2-6, 2-7, 2-8, 2-9 and 2-10 above, as in the following expressions.

$$P(G = Yes \cap H = Yes \cap R = Yes \cap W = Yes \cap S = Yes)$$
$$= P(G = Yes \mid R = Yes) P(H = Yes \mid R = Yes \cap S = Yes) P(R = Yes) P(W = Yes \mid R = Yes) P(S = Yes)$$
$$= (1-t) * 1 * 0.1 * 0.99 * 0.1 = 0.0099(1-t) . \tag{2-17}$$

Using equations (2-15), (2-16) and (2-17), we can get our final expression for $P(h_s \mid e=\{e_H, e_G\}) = \frac{P(h_s \cap e_H \cap e_G)}{p(e_H \cap e_G)}$ as in the following expressions.

$$P(h_s \cap e_H \cap e_G) = -0.01t + 0.0181 . \tag{2-18}$$

$$P(e_H \cap e_G) = -0.0991t + 0.1072 . \tag{2-19}$$

$$P(h_s \mid e=\{e_H, e_G\}) = \frac{P(h_s \cap e_H \cap e_G)}{p(e_H \cap e_G)} = \frac{-0.01t + 0.0181}{-0.0991t + 0.1072} . \tag{2-20}$$

Based upon equation (2-20), the sensitivity to a parameter in this example is shown in Figure 2-6. Based upon Figure 2-6, the conclusion is that the results of the BBN model (i.e., optimal decision) is not sensitive to parameters as long as their values are within a reasonable range.

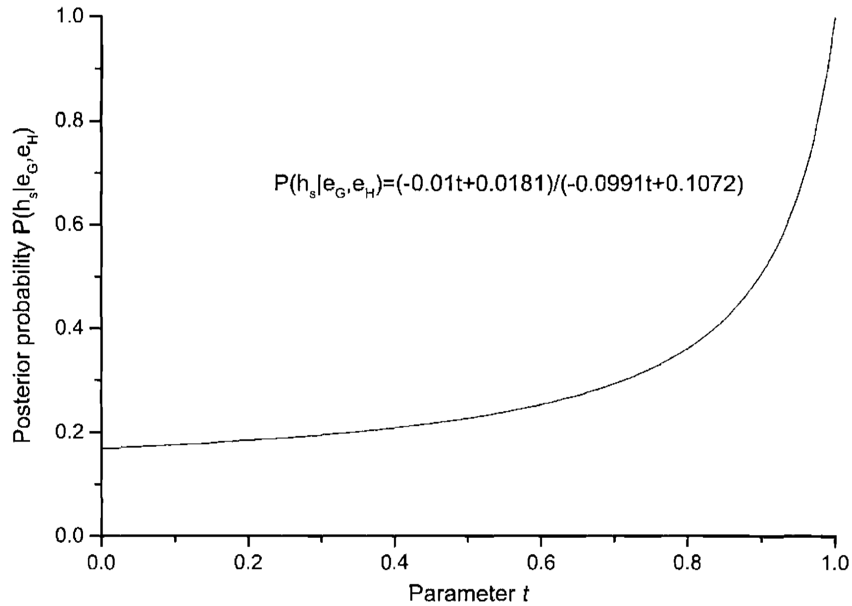


Figure 2-6. Sensitivity to parameter

2.3 Modeling techniques

2.3.1 Undirected relationships

It may happen that the BBN model must have dependent relationships among variables, using the example A, B, C in Figure 2-7, but the explicit dependencies in the BBN modeling are neither desirable nor possible to attach directions to them. In that case the BBN model is called a "Chain graph" and may invoke a cyclic explicit model as shown in Figure 2-7. This difficulty may be overcome by using the undirected relationships method (i.e., conditional dependence) described in the following example.

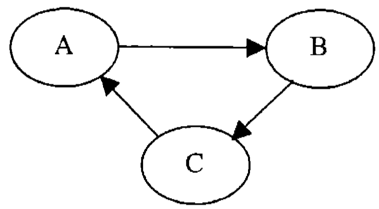


Figure 2-7. Chain graph in the BBN

In the situation above, add a new factor D with two states 'Yes' and 'No' and let the factors A, B and C be parents of the factor D as shown in Figure 2-8. Then it is possible to make the dependent relationships a constraint on factor D and input evidence 'Yes' (the dotted line in Figure 2-8) to factor D to activate these dependent relationships.

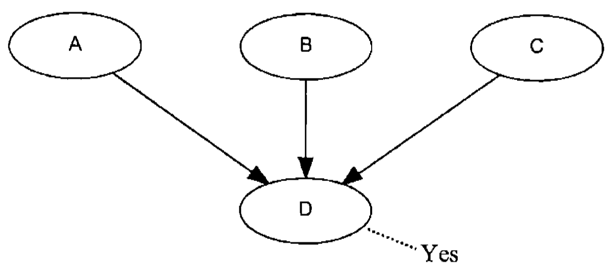


Figure 2-8. Undirected relations method in the BBN model

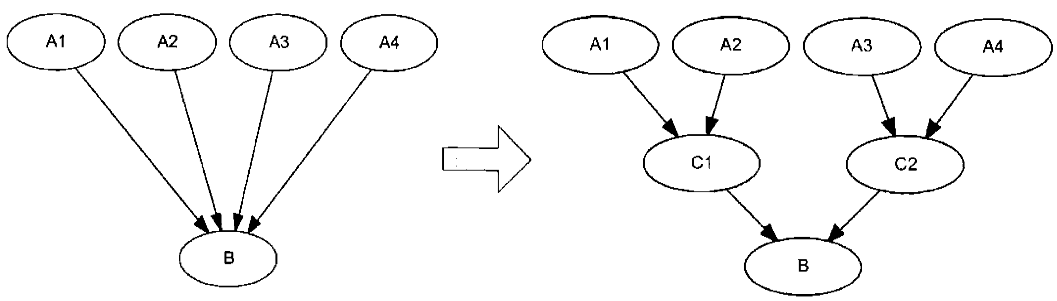
To enter the conditional probability values into the CPT for factor *D*, let *R (A, B, C)* describe the dependence relationships among *A*, *B* and *C* in [0, 1]. For example, if the dependent relationship is $P\ (A=a_1,\ B=b_1,\ C=c_1) = 0$, which means the state of $A=a_1$, $B=b_1$, $C=c_1$ is impossible, then $R\ (A=a_1,\ B=b_1,\ C=c_1) = 0$. Then input the following conditional probability values into the CPT for factor *D* and as well as evidence 'Yes'.

$$
\begin{aligned}
&P(D = Yes \mid A,B,C) = R(A,B,C) \\
&P(D = No \mid A,B,C) = 1 - R(A,B,C)\,.
\end{aligned}
\tag{2-21}
$$

2.3.2 Divorcing

One big problem that BBN modeling has is the large number of conditional probability needed to define the strength of dependencies among factors. The number of conditional probability needed grows exponentially according to the number of parent factors (the factors having causal relationship with another factor, i.e., dependency) and the state number of the factor itself. In the situation of many parent factors, the 'Divorcing' modeling method can reduce the number of conditional probability needed as described below.

Let $A_1, A_2, \ldots, A_n$ be a list of factors all of which are causes (i.e., parent factors) of factor B. You have to specify the conditional probability values $P(B \mid A_1, A_2, \ldots, A_n)$ to describe the behavior of B. This might result in a large knowledge-acquisition process task ahead of you. To reduce such a huge task, use the divorcing technique; the set of parents $A_1, A_2, \ldots, A_i$ for B are separated from the parents $A_{i+1}\ A_{i+2}, \ldots, A_n$ by introducing mediating factors C_1 and C_2, making C_1 and C_2 child factors of $A_1, A_2, \ldots, A_n$ and parent factors of B as shown in Figure 2-9 (for example, 4 parent factors, i.e., n=4).



Model A Model B

Figure 2-9. Divorcing modeling method

Suppose all factors have three states, then the number of conditional probability needed to describe factor B is 3×3×3×3×3 = 243 (i.e., the number of states of $A_1 \times A_2 \times A_3 \times A_4 \times$the number of state B) in model A and (3×3×3)×2×3 = 162 (i.e., (the number of states of $A_1 \times A_2 \times$ the number of state C)×the number of intermediate factors (C_1 and C_2)× the number of state B) in model B as shown in Figure 2-9. The benefit in the number of conditional probability in this situation is 243 – 162 = 81. If the number of state of each factor increases then the benefit from the divorcing technique increases also.

A problem in the divorcing technique is how to group the patent factors. One solution to this problem is to group the parent factors that have a similar effect on the child factor. For example, in a bank mortgage loan situation, there are a number of parent factors in deciding the loan eligibility, such as type of job, yearly income, other financial commitments, number and type of cars in the family, size and age of the house, price of the house and type of environment. (Jensen F. V., 2001) In this situation, the factors regarding the house can be grouped and have a common mediating factor describing the state of the house, and the factors regarding the financial factors can be grouped and describe financial ability. Then the conditional probabilities to loan eligibility can be obtained from the knowledge of the relationship between mediating factors and loan eligibility.

2.3.3 Time stamped model

The BBN modeling may work with the domain that evolves over the time. In this situation, a discrete time stamp technique can be used; make a BBN model for each unit of time and connect them over time evolving. A piece of the model for each unit time is called a 'Time Slice'. Consider the following example for infected milk.

"Milk from a cow may be infected. To detect whether or not the milk is infected, a farmer has a test that may either give a positive or a negative test result. The test is not perfect. It may give a positive result on clean milk as well as a negative test

result on infected milk. From one day to another, the state of the milk can change. Cows with infected milk will heal over time and a clean cow has a risk of having infected milk the next day." (Jensen F. V., 2001)

In this example, suppose a farmer performs the test each day. After a week he has not only the current test result but also the six previous test results. For each day we have a time slice as shown in Figure 2-10. Then these seven time slice models can be connected such that past knowledge can be used for the current conclusion as in Figure 2-11.

Figure 2-10. Time slice model for each day

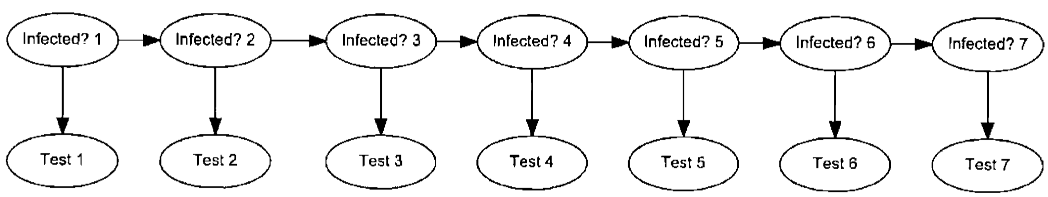


Figure 2-11. A seven-day model for milk test

2.4 Decision analysis with the BBN

2.4.1 What is the decision analysis?

More often than not, the decisions in our personal or professional life can be made without a lot of difficulty. Either the best choice is clear to us without much analysis or the decision is not important enough to warrant any great amount attention. In many cases, however, we probably find ourselves in a situation where we feel it is worth time and effort to think systematically and decide about the difference courses of action we might take. In difficult decision situations, the decision analysis technique would help solve the specific problem at hand, including the overall structure of the problem as well as our preferences and beliefs. (Clemen Robert T., Terence Reilly, 2001)

The obvious reason for using decision analysis is that carefully applying its methodologies can lead to better decisions. Decision analysis can help to better understand the problems and thus better decisions can be made. Such understanding should include the structure of the problem as well as the uncertainty and trade-offs inherent in the alternatives and outcomes. It may then improve the chances of a better outcome; more important, it would be less likely to experience unpleasant surprises in the form of outcomes that were either unforeseen or not fully understood. In another words, the decision analysis allows people to make effective decisions more consistently and to decrease the possibility of unpleasant outcomes, especially in difficult decision situations. Therefore, decision analysis is widely used in a number of areas: business, governmental policy, research & development programs, forecasting, medicine and so on.

Typically, the analysis of a decision problem under uncertainty requires the following steps. (Raiffa Howard, 1970)

1. List all variable options available
2. List all events that may possibly happen
3. Arrange them (options and events) in chronological order
4. Judge the consequences that result from the action and chances that any particular uncertain event will occur

After taking these steps – that is, systematically describe the problem and record judgments and preferences - we can begin to synthesize the information. Then, a series of calculations can be made and a certain strategy can be followed under a certain criterion (for example, i.e., the largest expected net benefit). Finally, this strategy is selected because it seems the best among the alternatives available to us.

2.4.2 Decision with the BBN

A BBN can serve as a model for a part of the world and the relationships in the model reflect casual impact between events. One of the important reasons for building the computer models (i.e., the expert systems) is to use them in deciding the best option among alternatives and taking the corresponding action. In the BBN, the probability values with action alternatives that are provided by the BBN can be used to support some kind of decision-making problem solving.

Let's suppose the following example.

"*An oil wildcatter must decide either to drill or not to drill. He is uncertain whether the hole is dry, wet or soaking. The wildcatter could take seismic sounding tests that will help determine the geological structure of the site. The sounding test will give a closed reflection pattern (indication of much oil), an open pattern (indication of some oil) or a diffuse pattern (almost no hope of oil).*" (Jensen F. V., 2001)

In this example, the wildcatter has to make two decisions, whether to take the seismic sounding tests costing $10k and whether to drill, costing $70k. The benefit gained from drilling is determined by the state of the drilled hole (dry, wet or soaking).

This example is modeled by the BBN as shown in Figure 2-10. It should be noted that the dependency direction is from 'Seismic' to 'Drill'. Since a decision node has no table assigned, this dependency direction does not represent a causal dependency. Instead it shows the system that when the decision of 'Drill' has to be made, the state of 'Seismic' should be known.

In Figure 2-12, the chance node of 'Oil' has three states: 1) dry, 2) wet and 3) soak; and the chance node 'Seismic' has three states: 1) closed, 2) open and 3) diffused. Two decision nodes have two states: 'Seismic test' – 1) yes and 2) no; and 'Drill' – 1) yes and 2) no. Tables 2-12, 2-13, 2-14 and 2-15 show the conditional probability values and cost and benefit values assigned in this example. Note that all values are borrowed from Jensen F. V., 2001.

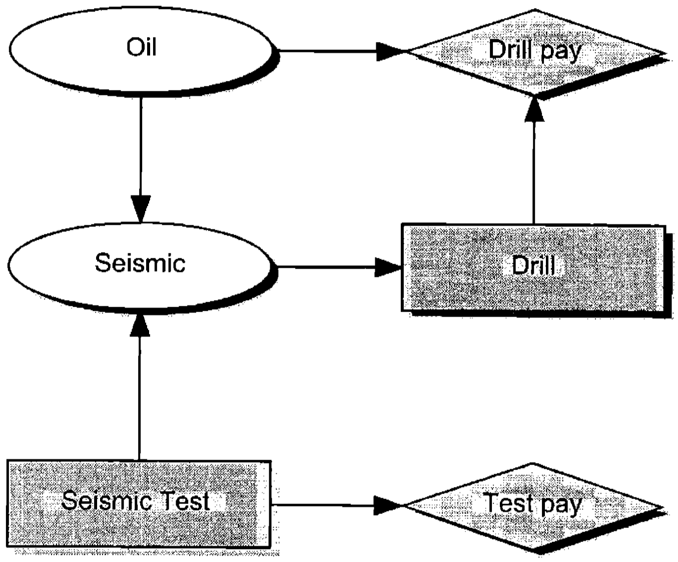


Figure 2-12. Oil wildcatter decision example with the BBN

Table 2-12. Probability values for 'Oil'

Oil = dry	Oil = wet	Oil = soak
0.5	0.3	0.2

Table 2-13. Conditional probability values for 'Seismic'

	Seismic test = yes			Seismic test = no		
	Oil = dry	Oil = wet	Oil = soak	Oil = dry	Oil = wet	Oil = soak
Seismic = closed	0.1	0.3	0.5	0.333	0.333	0.333
Seismic = open	0.3	0.4	0.4	0.333	0.333	0.333
Seismic = diffuse	0.6	0.3	0.1	0.333	0.333	0.333

Table 2-14. Benefit values for 'Drilling' (Unit = $)

Drill = yes			Drill = no		
Oil = dry	Oil = wet	Oil = soak	Oil = dry	Oil = wet	Oil = soak
-70k	50k	200k	0	0	0

Table 2-15. Cost values for 'Seismic Test' (Unit = $)

Seismic Test = yes	Seismic Test = no
-10k	0

In this example, it is assumed that the wildcatter acts in order to maximize the expected net benefit. In the case of not drilling, the expected net benefit is 0 no matter the state of 'Oil'. In the case of drilling without seismic sounding test, the wildcatter does not know the state of 'Oil' so he has to use the prior probability distribution of 'Oil'. Therefore, the expected net benefits of drilling without seismic sounding test and not drilling are expressed by following equation.

$$\text{ENB(Drill} \mid \text{no seismic test)} = \sum_{Oil} B(Drill \mid Oil)P(Oil) + C$$
$$= 0.5*(-70k) + 0.3*(50k) + 0.2*(200k) = 20k$$
$$\text{ENB(No drill} \mid \text{no seismic test)} = \sum_{Oil} B(noDrill \mid Oil)P(Oil) + C = 0\,. \qquad (2\text{-}22)$$

where

ENB : Expected Net Benefit

B : Benefit value

C : Cost value

P : Probability value

In the situation of not taking seismic sounding test, the wildcatter surely will choose a drilling and the maximum expected net benefit value of 20k$. Therefore, the Maximum Expected Net Benefit (MENB) in this situation is expressed as in equation (2-23).

$$\text{MENB(No seismic test)} = \max(\text{ENB(Drill} \mid \text{no seismic test)}, \text{ENB(No drill} \mid \text{no seismic test)})$$
$$= 20k\,. \qquad (2\text{-}23)$$

In the case of taking the seismic sounding test, the calculation would be more complicated. An example calculation for the worst case of seismic sounding test (i.e., diffuse result) is to, first, calculate the probability distribution of the 'Oil' state given the 'diffuse' of test results. Using the Bayes' theorem the probability distribution is obtained like follows.

$$P(dry, wet, soak \mid diffuse) = (0.731, 0.220, 0.049)$$
$$\text{ENB(Drill} \mid \text{diffuse)} = \sum_{Oil} B(Drill \mid Oil)P(Oil \mid diffuse) + C$$
$$= 0.731*(-70k) + 0.22*(50k) + 0.049*(200k) - 10k = -40.4k$$
$$\text{ENB(No drill} \mid \text{diffuse)} = \sum_{Oil} U(noDrill \mid Oil)P(Oil \mid diffuse) + C = -10k$$
$$\text{MENB(diffuse)} = -10k\,. \qquad (2\text{-}24)$$

The result says that not taking 'Drill' gives the MENB of -10k$ in the case of taking seismic sounding test and resulting in the 'diffuse' state. Table 2-16 shows the MENBs according to the seismic sounding test results.

Table 2-16. MENBs with seismic sounding test results (Unit = $)

Test result	Closed	Open	Diffuse
MEU	77.6k	22.9k	-10k

Based upon the MENB values in Table 2-16 and probability distribution of seismic sounding test results, the MENB value of taking seismic sounding tests could be evaluated as in equation (2-25). The MENB of this example can be calculated as in equation (2-26).

$$\text{MENB(Seismic test)} = 77.6k * 0.24 + 22.9k * 0.35 + (-10k) * 0.41 = 22.5k\,. \quad (2\text{-}25)$$

$$\text{MENB} = \max(\text{MENB(Seismic test)}, \text{MENB(No seismic test)}) = 22.5\text{k}\,. \quad (2\text{-}26)$$

Therefore, the wildcatter is advised to take seismic sounding test and then to determine whether to take drill or not, after obtaining the test result. When the result shows the state of the hole is closed or open, then the wildcatter is advised to drill. However, in the case of the 'diffuse' result, then the wildcatter should take the 'not drill' action. This advice is also illustrated in Figure 2-13, which shows the result in the classical decision tree approach.

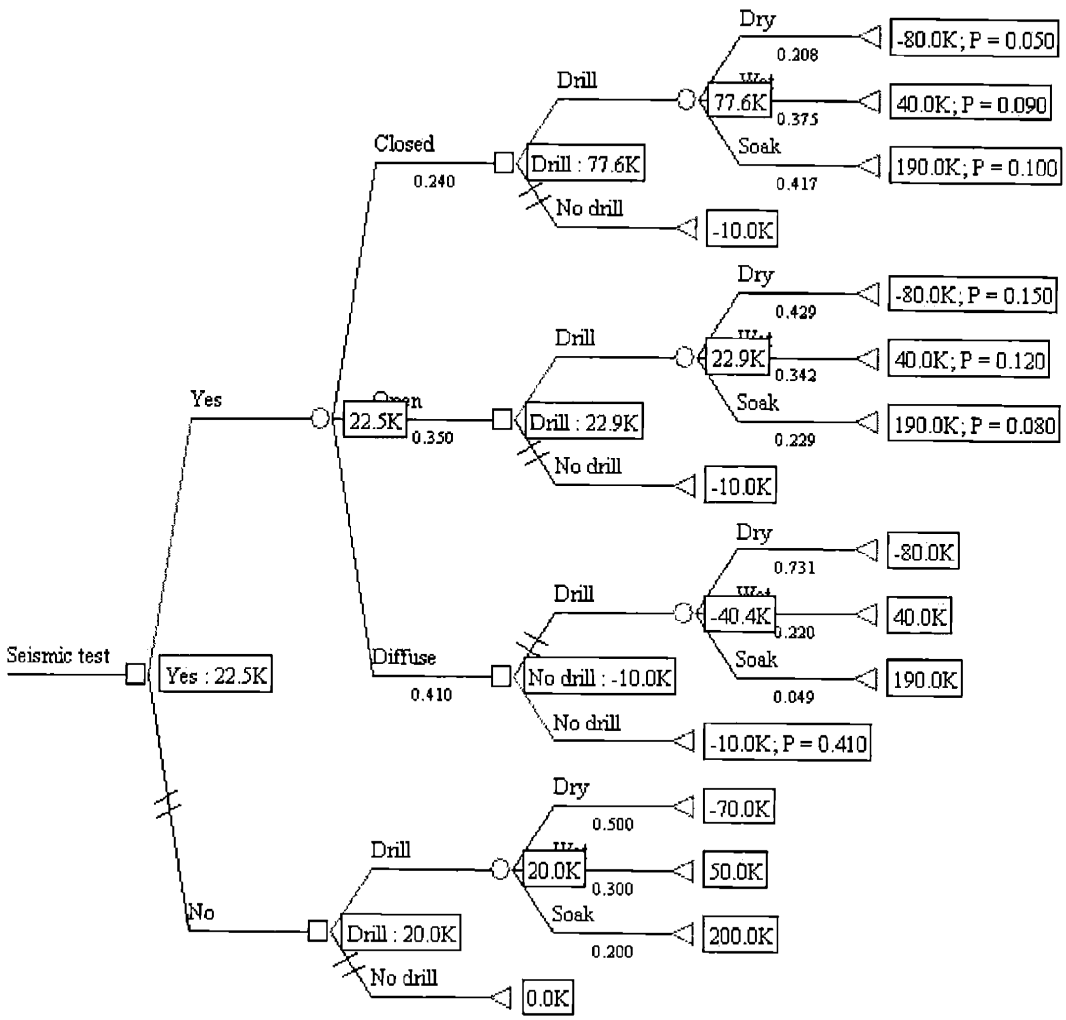


Figure 2-13. Wildcatter example in decision tree approach

The wildcatter example result in HUGIN (the name of the software for BBN modeling) is shown in Figure 2-14. It illustrates the same results of 20k$ of MEU of 'Drill' in the case of no seismic sounding test, and of 22.5k$ in the case of taking seismic sounding tests.

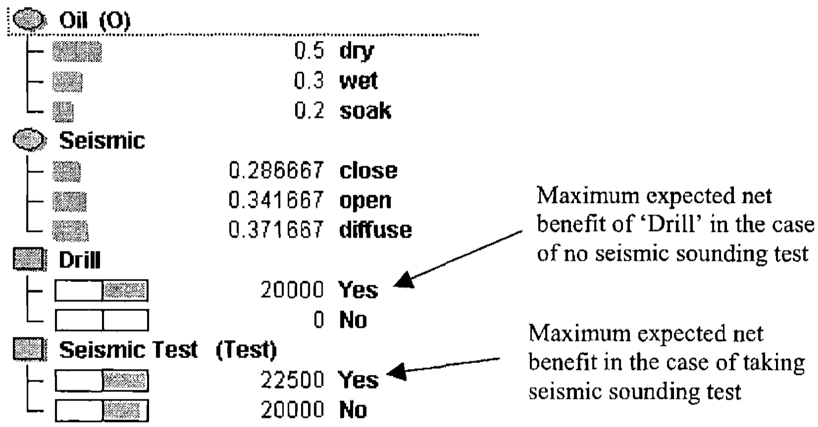


Figure 2-14. Wildcatter example result in HUGIN

CAHPTER 3.
DEVELOPMENT of BBNs for STEAM GENERATOR REPLACEMENT PROJECT MANAGEMENT

The growing need for improved project management technique points to the usefulness of a knowledge-base advisory system to help manager understand the status of project and optimize decisions. The work here demonstrates the framework of a reasoning system with improved ability in project management. Traditional rule-based approaches for expert systems are not adopted here since they are not well suited to the inherently uncertain environment and the complex relationships of project management. Rather, the BBN approach is employed as a high-level reasoning tool that is valuable for incorporating complexities and inherent uncertainties via use of probabilistic inference.

3.1 Project life cycle and important factors

The first step to build the BBN models for steam generator replacement project management is to identify the project life cycle and corresponding important factors for each individual work phase through continuous communications with the experts in this domain as shown in Tables 3-1 and 3-2. A project is usually divided into several project work phases in order to provide better management control and appropriate links to the ongoing operations of the performing organization. Collectively, the project phases are known as the project life cycle. (Duncan W. R., 1996)

Each project phase is marked by production of one or more products ("deliverables"). A deliverable is a tangible, verifiable work product such as a feasibility study, a detailed design or working prototype. The deliverable, hence the project work phases, are the part of a generally sequential logic designed to ensure proper definition of the product of the project. (Duncan W. R., 1996) Each phase normally includes a set of defined work products designed to establish such desired deliverables and level of management control. Typically, phases take their names from these items: start-up, design, construction, turnover and others as appropriate.

The project life cycle serves to define the beginning and the end of a project. Project life cycle generally defines:

- What technical work should be done in each phase?
- Who should be involved in each phase?
- The schedule of work from overall level of the project to very detailed level.
- The organization policies for each phases of work.

Table 3-1. Steam generator replacement project life cycle

Phase I	Phase II	Phase III	Phase IV	Phase V	Phase VI
Conceptual design	**Detailed design**	**Work package development**	**Site & Craft mobilization**	**Outage**	**Closeout**
- Conceptual cost, time & engineering design - Procurement planning	- Detailed cost, time & engineering design - Information Procurement	- Detailed work package development and procedure planning	- Delivery - Preparation - Testing	- Installation - Testing	- Final testing - Licensing - Maintenance
~ 9 months	~ 6 months	~ 21 months	~ 2 months	~ 3 months	~ 2 months
	~ 3 years				

Table 3-2. Important factors for each phase in steam generator replacement project

Phase I +	Phase II +	Phase III ++	Phase IV*	Phase V*	Phase VI ++
Conceptual design	**Detailed design**	**Work package development**	**Site & Craft mobilization**	**Outage**	**Closeout**
- Time - Cost - Scope	- Time - Cost - Scope - Client	- Time - Cost - Scope - Quality - Client	- Time - Cost - Scope - Quality - Human - Material - Client	- Time - Cost - Scope - Quality - Human - Material - Client	- Time - Cost - Quality - Client

+ In theses phases, cost has proportional relationship with manpower.

++ We do not need explicit modeling this phase since the project is hand over to client after phase V.

* Human: Human resource, Material: Material resource, Client: Client satisfaction

The steam generator replacement project is divided into six work phases: conceptual design, detailed design, work package development, site & craft mobilization, outage and closeout, as identified in Tables 3-1 and 3-2. At the end of the outage phase or startup of the closeout phase, the project is almost ready to deliver to the client since all major work has been finished. Thus, it is decided that there is no need for explicit modeling of the closeout phase. The seven factors in Table 3-2 (time, cost, scope, quality, human resource, material and client satisfaction) were selected as input factors for steam generator replacement project management through iteration with domain experts. These seven factors should be monitored throughout the entire project lifetime from overall summary level of the project along with detailed level down into the Work Breakdown Structure (WBS), except in the earlier phases due to the characteristics of the steam generator replacement project (e.g., no large amount of human and material resource needs in the earlier phases). Based upon the description above, the steam generator project life cycle and important input factors in each individual work phase are identified as in Figure 3-1.

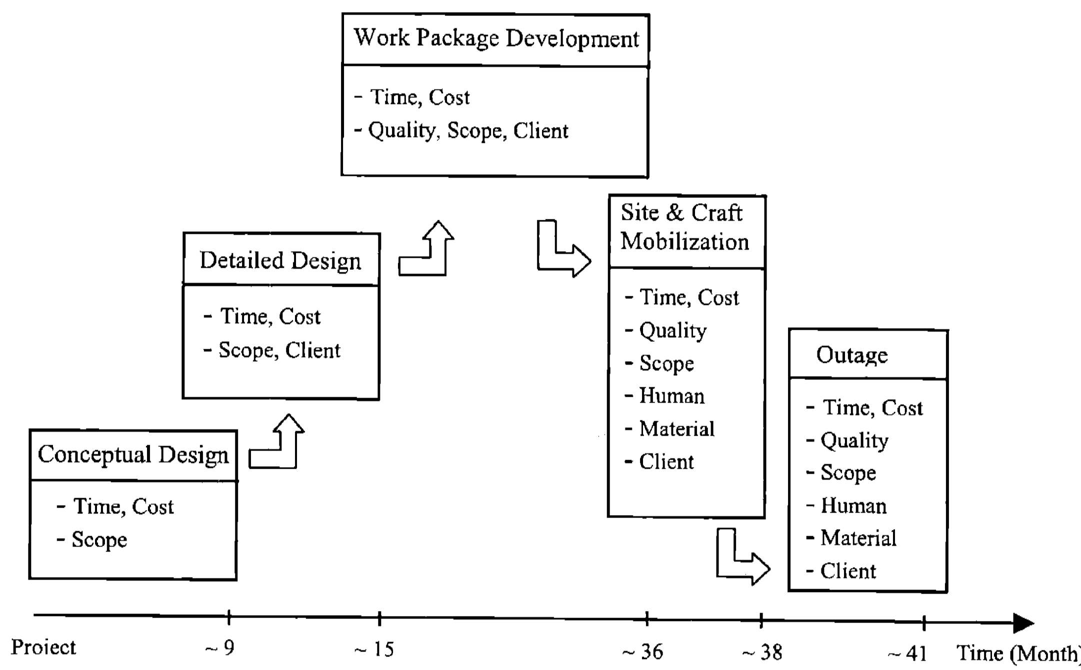


Figure 3-1. Steam generator project life cycle and important input factors

Output factors that can measure the overall project performance, the Schedule Performance Index (SPI), Cost Performance Index (CPI) and Profit in EAC (Estimate At Completion) Index (PI) are selected through discussion with domain experts. These three indices are widely used for project management. The SPI is used to forecast the project completion date and the CPI for project cost at completion compared to the original schedule. For example, if the SPI value is equal to 0.7, then the project is only 70% completed for the scheduled period. If the CPI value is equal to 0.7, then the project budget is overrun by 1/0.7 % (143%) of scheduled budget to-date. Therefore the values of these two project performance indices, SPI and CPI, should always be kept as close to unity or over unity. Three output factors are defined in equation (3-1).

Each individual input factor is defined as follows.

1. Time compliance – the degree to which the project objectives are as planned (measured by the TPI (Time Performance Index)).
2. Cost compliance – the degree to which the project objectives are completed within the approved budget (measured by the CDI (Cost Deviation Index)). Cost compliance is primarily concerned with the cost of the resources needed to complete the project activities.
3. Scope compliance – the degree to which the current project scope differs from that of the project plan (measured by the SCPI (SCope Performance Index)). Scope is defined as the work that must be done in order to deliver a product with the specified features and functions.
4. Initial quality (initial rework fraction) – the fraction of work being performed that is completed successfully in the initial work iteration (measured by the QPI (Quality Performance Index)). Quality management is defined as the process to ensure that predefined criteria, standards, regulations and/or client's requirements are satisfied by means such as quality planning, quality control, quality assurance and quality improvement.

5. Human resource management – the processes required to ensure that an adequate set of workers is committed to the project (measured by the HRI (Human Resource Index)). Its scope includes all the project participants – sponsors, customers, individual contributors and others.
6. Material (Procurement) management – the processes required to ensure that an adequate set of goods and services from inside and outside the performing organization will be available to the project as needed (measured by the MRI (Material Resource Index)). Material is defined as resources other than human resource and money, such as information and equipment.
7. Client satisfaction – Client satisfaction is measured by a rating of the project on the project performance (measured by Non-Conformance Report indirectly or meeting with client directly).

The performance indices of seven inputs and three outputs of the BBN for steam generator replacement project management described above are defined as follows.

Three project performance indices inferred from seven important factors – output of the BBN model for steam generator replacement project management

$$CPI = \frac{BCWP}{ACWP} \quad , \quad SPI = \frac{BCWP}{BCWS} \quad , \quad PI = \frac{SPEAC + CPEAC}{SPEAC} . \qquad (3\text{-}1)$$

where

$ACWP$: Actual Cost of Work Performed in Figure 3-2

$BCWS$: Budgeted Cost of Work Scheduled in Figure 3-2

$BCWP$: Budgeted Cost of Work Performed in Figure 3-2

= $BCWS$*(Fraction of work completed)

$CPEAC$: Changed Profit in EAC

= Positive value if profit increases

= Negative value if profit decreases

$SPEAC$: Scheduled Profit in EAC

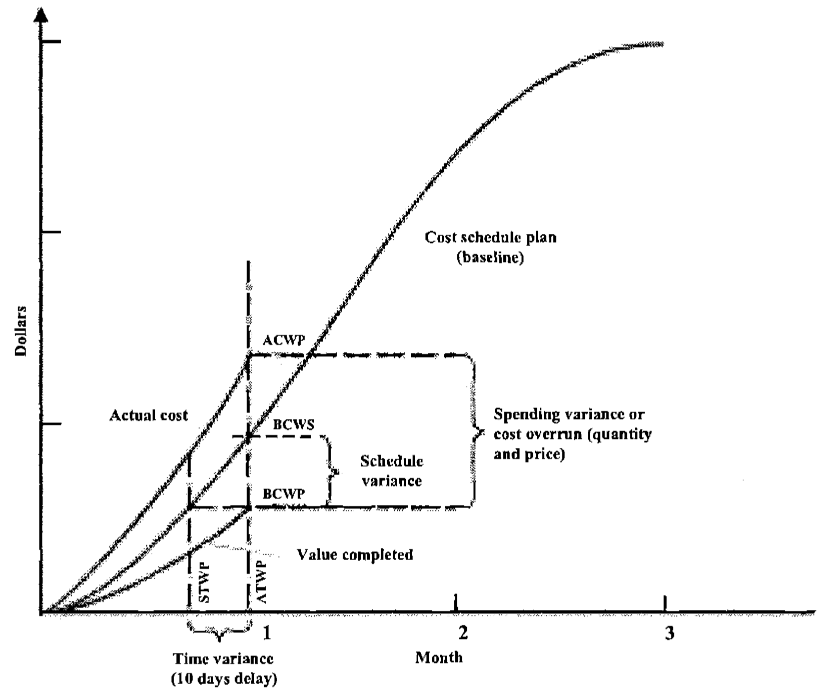


Figure 3-2. Earned value chart (Meredith Jack R., S. J. Mantel Jr., 2000)

The performance indices for six important factors – entered as evidences in the BBN model

$$TPI = \frac{STWP}{ATWP} \quad , \quad CDI = \frac{BCWS}{ACWP}$$

$$SCPI = \frac{BCWS}{BCWS + CCSC} \quad , \quad QPI = \frac{BCWS}{BCWS + CCWQ}$$

$$HRI = \frac{SHR - AHR}{SHR} \quad , \quad MRI = \frac{SMR - AMR}{SMR} \quad . \qquad (3\text{-}2)$$

where

AHR : Absent Human but needed Resource

$$= \int_0^T \sum_i \sum_j x_{i,j}(t)dt$$

i : Worker group (e.g., manager, supervisor, etc.)

j : Experience group in each worker group (e.g., five-year experienced manager, senior engineer, etc.)

$x_{i,j}(t)$: Absent but needed number of humans in group i, j at time t

$= N_{i,j}(t) - n_{i,i}(t)$, if $N_{i,j}(t) \geq n_{i,j}(t)$

$= 0$, if $N_{i,j}(t) < n_{i,j}(t)$

where

$N_{i,j}(t)$: Scheduled number of humans in group i, j at time t

$n_{i,j}(t)$: Actual number of humans in group i, j at time t

T : Time of interest (current time)

AMR : Absent Material but needed Resource

$$= \sum_i D_i$$

i : Material group (e.g., information, electrical equipment, etc.)

D_i : Absent but needed material due to procurement failure

$= S_i - A_i$, if $S_i \geq A_i$ (i.e., delayed or on-time procurement)

$= 0$, if $S_i < A_i$ (i.e., early procurement)

where

A_i : Actual material procured quantities in group i over time $(0,T)$

S_i : Scheduled material procured quantities in group i over time $(0,T)$

T : Time of interest (current time)

$ATWP$: Actual Time of Work Performed in Figure 3-2

$BCWS$: Budgeted Cost of Work Scheduled

$CCSC$: Changed Cost due to Scope Change (i.e., the amount of increased cost portion from $BCWS$ when scope change happens – new work)

$CCWQ$: Changed Cost due to inadequate Work Quality (i.e., the amount of increased cost portion from $BCWS$ when quality problem happens – rework)

SHR : Scheduled Human Resource

$$= \int_0^T \sum_i \sum_j N_{i,j}(t)dt$$

i : Worker group (e.g., manager, supervisor, etc.)

j : Experience group in each worker group (e.g., five-year experienced manager, etc.)

$N_{i,j}(t)$: Scheduled number of humans in group i, j at time t

T : Time of interest (current time)

SMR : Scheduled Material Resource

$$= \sum_i S_i$$

i : Material group (e.g., information, electrical equipments, etc.)

S_i : Scheduled material procured quantities in group i over time $(0,T)$

T : Time of interest (current time)

STWP : Scheduled Time of Work Performed in Figure 3-2

3.2 Dependency check

For the BBN modeling with the seven input factors mentioned in Section 3.1, identification should be made of the factors having strong dependency on the main project state indicators, CPI and SPI, in the preparation step to reduce following inherent BBN limitations. One inherent limitation of the BBN approach is the large number of conditional probability values needed to define the behavior of factors in the domain. The number of conditional probability values needed increases exponentially according to the number of parent factors (the factors having causal relation to another factor, i.e., dependency) and the state number of factors itself. Therefore, if factors that are weak or not dependent on project performance indicators can be identified, labor needed to define the conditional probability in BBN modeling can be reduced. Therefore identification of the dependencies of factors using pair-wise comparison among the seven factors and the relative dependency priority of each factor are being attempted.

Pairwise comparison

A way of assessing consistency among the probability values elicited from experts is a pair-wise comparison. The following brief description of the method is given by T. L. Saaty, 1996.

Given the four elements, A, B, C, D and one other element, E, in order to know the relative strength of influence of four elements on element E, perform six pairwise comparisons {(A, B), (A, C), (A, D), (B, C), (B, D) and (C, D)} in their strength of influence on E. Insert the "predefined agreed upon scores", reflecting the comparison judgment in either a subjective or objective way, into a comparison matrix and find the eigenvector[2] with the largest eigenvalue[3]. The eigenvector provides the priority ordering and the eigenvalue is a measure of the consistency of the judgment.

Example (Saaty T. L., 1996)

"Let us determine a priority scale in the following example. Let A, B, C, D stand for chairs in different positions from the light. We develop a priority scale of relative brightness for the chairs. Judgments will be obtained from an individual who stands by the light source and is asked, for example, "How much brighter is chair B than chair C?" He will then give one of the answers from predefined agreed upon scores and this judgment will be entered in the matrix in position (B, C). By convention, the comparison of strength is always of an activity appearing in the column on the left against an activity appearing in the row on top. In this example, we have the pairwise comparison matrix with four rows and four columns (a 4×4 matrix)."

The "predefined agreed upon scores" in this example are the following. Given elements A and B; if

A and B are equally bright, insert 1
A is weakly brighter than B, insert 3
A is strongly brighter than B, insert 5
A is very strongly brighter than B, insert 7

[2, 3] Given n×n matrix A and vector x equation, $Ax = \lambda x$, a value of λ for which has a solution $x \neq 0$ is called an eigenvalue and corresponding solutions $x \neq 0$ are called eigenvectors of matrix A corresponding to eigenvalue λ.

A is absolutely brighter than B, insert 9

An element is equally important when compared with itself, so where the diagonal position, for example (A, A), insert 1. Thus the main diagonal of a matrix must consist of 1's. Insert the appropriate reciprocal 1, 1/3, … , or 1/9 where the column of A meets the row of B, i.e., position (B, A) for the reverse comparison of B with A, i.e., (A, B). The numbers 2,4,6,8 and their reciprocals are used to facilitate compromising between slightly different judgments.

For example, if the judgments on the brightness are as follows, then we can obtain the following pairwise comparison matrix.

A is weakly brighter than B
C is strongly brighter than A
A is strongly brighter than D
B is weakly brighter than C
B is very strongly brighter than D
C is absolutely brighter than D

Table 3-3. Comparison matrix in the relative brightness example

	A	B	C	D
A	1	3	1/5	5
B	1/3	1	3	7
C	5	1/3	1	9
D	1/5	1/7	1/9	1

Survey questionnaire

You may think of this dependency check as a kind of a sensitivity study. Project performance indices (CPI and SPI) are functions of all or some of the seven important factors of Figure 3-1 (time, cost, scope, quality, human resource, material and client satisfaction). Therefore you can interpret the dependency check statement "Perform the pair-wise comparison of the dependency of a specific project performance index upon two factors (for example, time and cost)" into following steps.

1. Suppose the situation that all three project performance indices and the seven important factors show a normal state (i.e., planned value).
2. Change the first factor of the set (i.e., A in the comparison set (A, B)) by the corresponding value from the "change degree list" below and observe the resultant change in the specific project performance index.
3. Back the first factor into its normal state and change another factor (i.e., B in the comparison set (A, B)) by the corresponding value from the "change degree list" below and observe the resultant change in the specific project performance index.
4. Compare those two results and insert the "predefined agreed upon scores" into the (A, B) position and the reciprocal of the "predefined agreed upon score" into the (B, A) position or vice versa. Note that the (A, B) set means the position of row A and column B in the matrix.

The "change degree list" used in this comparison is as follows.

1. Time: 10% delay from planned value
2. Cost: 10% overbudget from planned value
3. Scope: 10% increase of work range from planned value, so 10% increase of new work
4. Quality: 10% below the planned value (standard), so 10% increase of rework
5. Human: 10% less than the planned value
6. Material: 10% less than the planned value

7. Client: 10% below full satisfaction (i.e., 90% satisfaction)

The “predefined agreed upon scores” used in this comparison are as follows.

A and B are equally dependent (sensitive), insert 1
A is weakly more dependent (sensitive) than B, insert 3
A is strongly more dependent (sensitive) than B, insert 5
A is very strongly more dependent (sensitive) than B, insert 7
A is absolutely more dependent (sensitive) than B, insert 9

Dependency check of the CPI

Pease give the score of dependency of the CPI upon factors.

Table 3-4. Comparison matrix of the CPI

B / A	Time	Cost	Scope	Quality	Human*	Material*	Client*
Time	1						
Cost		1					
Scope			1				
Quality				1			
Human*					1		
Material*						1	
Client*							1

* Human: human resource, Material: material resource, Client: client satisfaction

<u>Dependency check of the SPI</u>

Please give the score of dependency of the SPI upon factors.

Table 3-5. Comparison matrix of the SPI

B / A	Time	Cost	Scope	Quality	Human*	Material*	Client*
Time	1						
Cost		1					
Scope			1				
Quality				1			
Human*					1		
Material*						1	
Client*							1

* Human: human resource, Material: material resource, Client: client satisfaction

Dependency check survey results by expert

Tables 3-6 and 3-7 show the pair-wise comparison results by domain experts.

Table 3-6. Resultant comparison matrix of the CPI

B / A	Time	Cost	Scope	Quality	Human*	Material*	Client*
Time	1	1/3	3	3	7	5	5
Cost	3	1	5	5	9	7	9
Scope	1/3	1/5	1	1/3	5	3	3
Quality	1/3	1/5	3	1	7	5	5
Human*	1/7	1/9	1/5	1/7	1	1/3	1/3
Material*	1/5	1/7	1/3	1/5	3	1	3
Client*	1/5	1/9	1/3	1/5	3	1/3	1

* Human: human resource, Material: material resource, Client: client satisfaction

Table 3-7. Resultant comparison matrix of the SPI

A \ B	Time	Cost	Scope	Quality	Human*	Material*	Client*
Time	1	3	5	3	7	7	9
Cost	1/3	1	5	3	7	7	9
Scope	1/5	1/5	1	1/3	3	3	5
Quality	1/3	1/3	3	1	5	5	7
Human*	1/7	1/7	1/3	1/5	1	3	5
Material*	1/7	1/7	1/3	1/5	1/3	1	3
Client*	1/9	1/9	1/5	1/7	1/5	1/3	1

* Human: human resource, Material: material resource, Client: client satisfaction

Dependency priority vectors

Based upon the comparison matrices of the SPI and the CPI by experts as shown in Tables 3-6 and 3-7, the dependency priority vectors can be computed. For the CPI, the eigenvector (w) corresponding to the maximum eigenvalue and the normalized priority vector (w_N) are as follows in equation (3-3) and shown in Figure 3-3. The resulting priority vector of the CPI is true since the consistency ratio is within the acceptable range as illustrated in equation (3-3).

$$w = \begin{pmatrix} Time \\ Cost \\ Scope \\ Quality \\ Human \\ Material \\ Client \end{pmatrix} = \begin{pmatrix} 0.670 \\ 1.267 \\ 0.267 \\ 0.466 \\ 0.067 \\ 0.155 \\ 0.108 \end{pmatrix} \xrightarrow{\text{Normalization}} w_N = \begin{pmatrix} Time \\ Cost \\ Scope \\ Quality \\ Human \\ Material \\ Client \end{pmatrix} = \begin{pmatrix} 0.223 \\ 0.422 \\ 0.089 \\ 0.155 \\ 0.023 \\ 0.052 \\ 0.036 \end{pmatrix} \quad (3\text{-}3)$$

where

Maximum eigenvalue, $\lambda_{max} = 7.585$

Consistency Index, CI = (λ_{max} –n)/(n-1) = 0.097

Consistency Ratio, CR = CI/RI = (0.097/1.32) = 0.073 (Acceptable if less than 0.1)

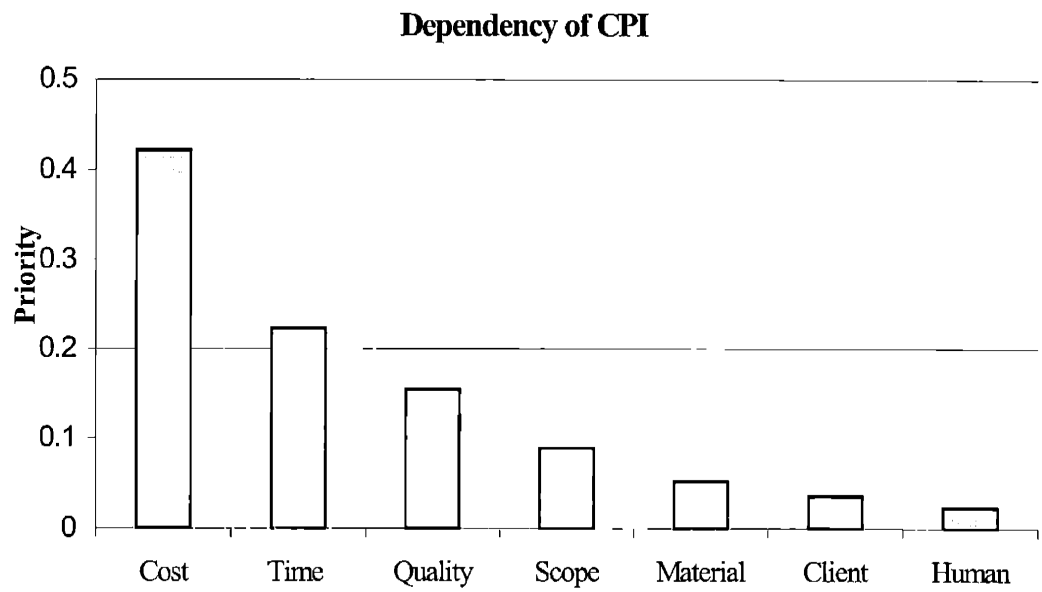


Figure 3-3. Normalized dependency priority vector of the CPI

For the SPI, the eigenvector (w) corresponding to the maximum eigenvalue and the normalized priority vector (w_N) are as follows in equation (3-4) and illustrated in Figure 3-4. Like in the case of the CPI, the resulting priority vector of the SPI is reliable since the consistency ratio is within the acceptable range as shown in equation (3-4).

$$w = \begin{pmatrix} Time \\ Cost \\ Scope \\ Quality \\ Human \\ Material \\ Client \end{pmatrix} = \begin{pmatrix} -3.987 \\ -2.884 \\ -0.873 \\ -1.667 \\ -0.568 \\ -0.366 \\ -0.213 \end{pmatrix} \xrightarrow{\text{Normalization}} w_N = \begin{pmatrix} Time \\ Cost \\ Scope \\ Quality \\ Human \\ Material \\ Client \end{pmatrix} = \begin{pmatrix} 0.377 \\ 0.273 \\ 0.083 \\ 0.158 \\ 0.054 \\ 0.035 \\ 0.020 \end{pmatrix} \quad (3\text{-}4)$$

where

Maximum eigenvalue, λ_{max} = 7.639

Consistency Index, CI = $(\lambda_{max} - n)/(n-1) = 0.106$

Consistency Ratio, CR = CI/RI = (0.106/1.32) = 0.080 (Acceptable if less than 0.1)

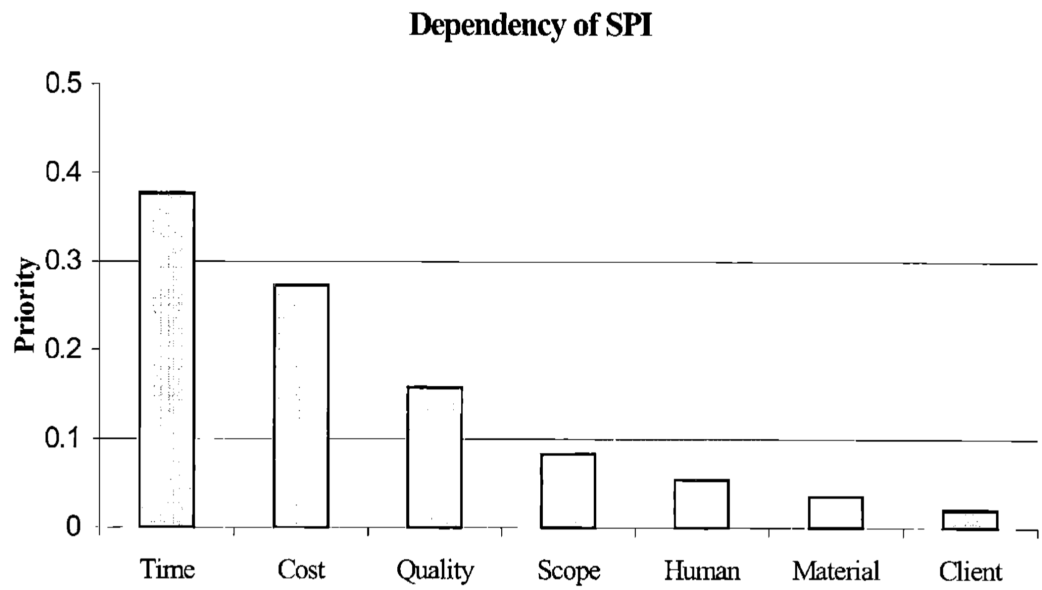


Figure 3-4. Normalized dependency priority vector of the SPI

As expected, time and cost are the most dependent factors of SPI and CPI. The difference between SPI and CPI is that cost takes the first dependent place of CPI and time of SPI. Based upon the results in Figures 3-3 and 3-4, time and cost are grouped into a 'Prime importance group', quality as a 'Medium importance group' and the other factors as a 'Minor importance group'.

3.3 BBN modeling for single-work task level

With the identified important input and output factors in the BBN for steam generator replacement project management in Figure 3-1 and dependency check survey results in Figures 3-3 and 3-4, a time slice BBN model for single-work task level has been developed as in Figure 3-5. Current time and cost factors impact on the current SPI and CPI values directly because they are prime dependence group members. The other five factors have indirect impacts on the SPI and CPI. Quality and scope impact through the 'Work?' factor and human and material through the 'Absent?' factor. These two factors of 'Work?' and 'Absent?' are called mediating factors and are used to reduce the number of conditional probability values needed, as mentioned in Section 2.3.2. The 'Work?' factor has the means that 'Do we have rework resulting from inadequate work quality or new work resulting from scope change?' and the 'Absent?' factor that 'Do we have resource (Human or Material) gap between schedule and actual value?' Client satisfaction factor does not impact on the current SPI and CPI, instead it impacts on quality and scope factors of next time step as seen in Figure 3-5.

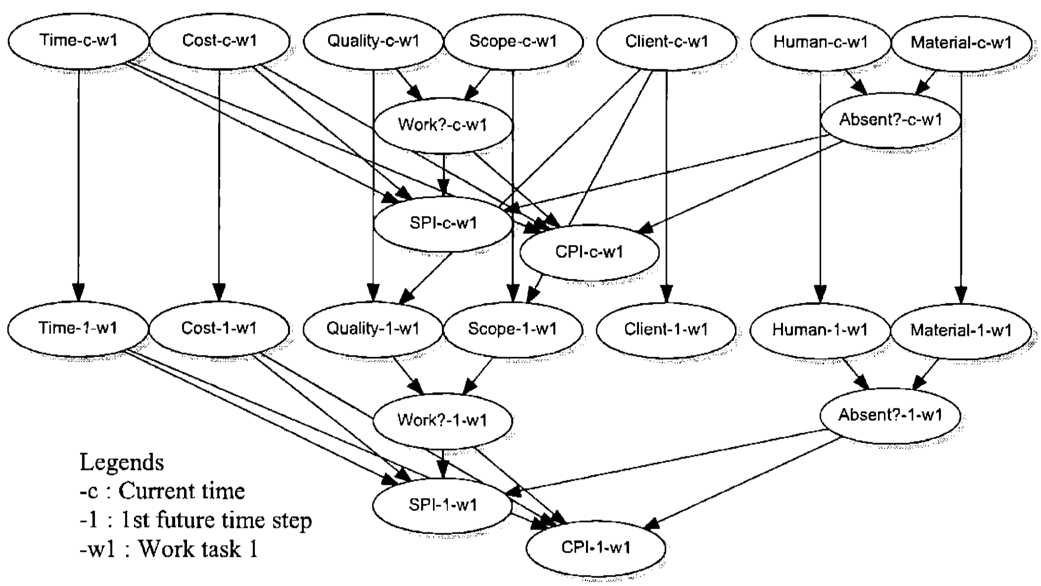


Figure 3-5. Structure of the time slice BBN model for single-work task level with seven important input factors

3.3.1 Predictive mode BBN

Based upon the time slice BBN model in Figure 3-5 in Section 3.3 and the time-stamped modeling technique described in Section 2.3.3, the predictive mode BBN for a single-work task for three future time steps has been developed as shown in Figure 3-6.

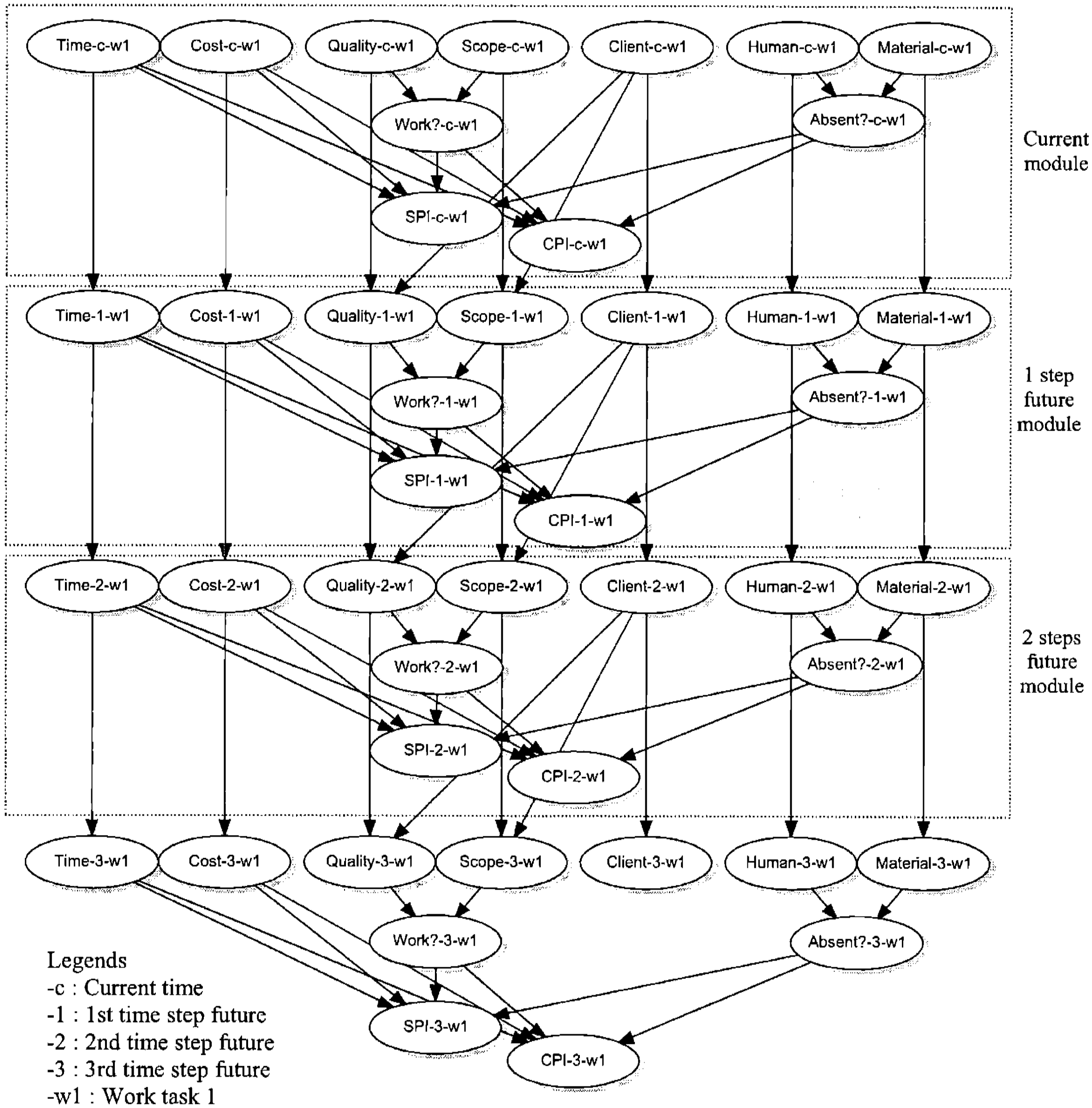


Figure 3-6. Structure of the single-work task predictive mode with seven important input factors

In the predictive mode BBN for a single-work task, the BBN can give us the future prior and posterior project performance state probability distributions of output factors depending on given current evidence. Current evidence reflecting the knowledge and information about current project status can be entered into the current module depicted in Figure 3-6. Then the predictive mode BBN updates the probability distributions of all other factors in the BBN domain using Bayes' theorem and displays the updated project performance probability distributions in one step, two-step and three-step future modules. It should be noted that these prediction values are under assumption that there will be no intervening action by management from current time into the future. The updating procedure is illustrated in Section 2.1. Only up to three-step future modules can be displayed in Figure 3-6 due to lack of space, but this model can be developed for as many future steps as needed, theoretically. In practice, however, the number of future steps is limited due to computer hardware limitation, which will be discussed in a later section.

Based upon identified important factors for each work phase in Figure 3-1, the predictive mode BBNs for five different work phases have been developed. The structures of the predictive mode BBNs for different work phases are similar to each other except for considered important input factors. For example, Figure 3-7 illustrates the predictive BBN for the conceptual design work phase.

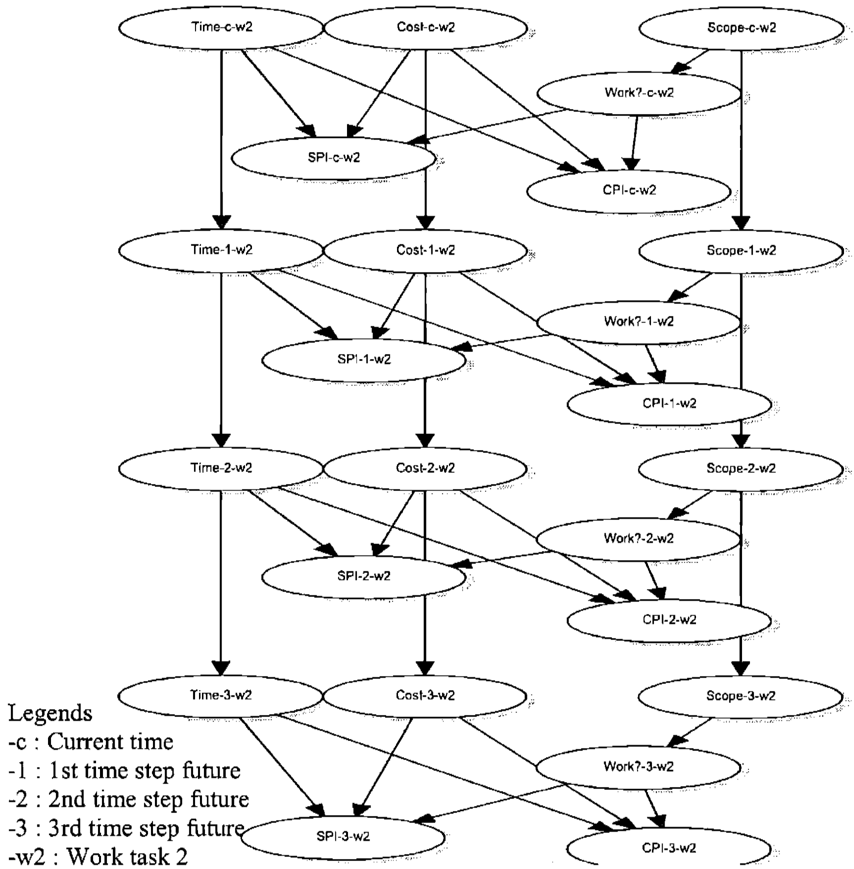


Figure 3-7. Structure of the single-work task predictive mode in the Conceptual Design work phase

3.3.2 Advisory mode BBN

As in the predictive mode in Section 3.3.1, the advisory mode BBN for the single-work task has been developed using a time-slice and action alternatives that were identified from discussion with domain experts, as in Figure 3-8. The structure of the advisory mode is similar to that of the predictive mode. The difference between the two modes is the fact that both previous step factors and action taken by the project manager affect the next step factors at the same time in the advisory mode BBN, while only the previous step factors in the predictive mode BBN are used.

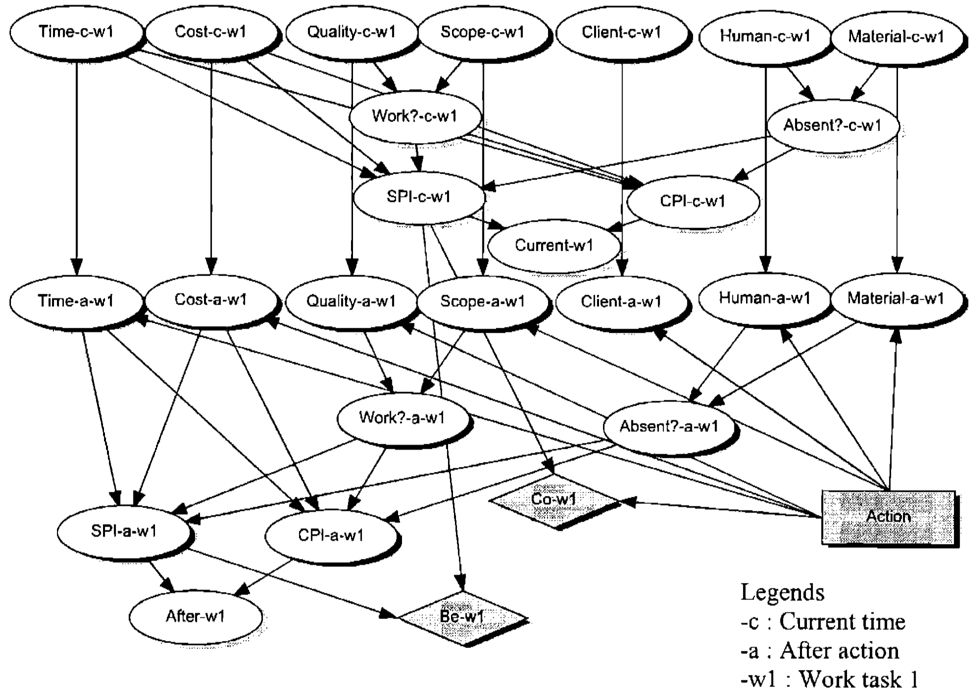


Figure 3-8. Structure of a single-work task advisory mode with seven important input factors

The actions alternative that the project manager may take during the project lifetime are reviewed and selected through discussions with domain experts. There may be many actions alternative but only the major ones are selected for inclusion in our model. First, the major action alternatives for an individual work task level are selected and then, among those selected, they are grouped into overall project level action alternatives. The selected action alternatives for both the individual work task level and the overall project level are listed in Table 3-8. These actions are considered in the advisory mode BBN for action alternatives. It should be noted that the overall project level action does not have a real action effect, rather when the project manager selects one from the overall project level alternatives, considering both the overall project level and the individual work task level performance status, then the corresponding individual work task level action is realized.

Table 3-8. Action alternatives for both the individual work task level and the overall project level

Overall project level	Individual work task level
Resource change	Resource transfer
Human resource change	Hire from job market
	Hire from contractor
	Overtime work
	Layoff person
Scope or schedule change	Scope reduction
Process change	Introduction new technology
	Equipment reduction
Do thing	Do thing

In the advisory mode BBN for a single-work task, the BBN can identify the expected optimal action for the single-work task among alternatives under given current conditions and the updated probability distributions after taking action. This advice on the expected optimal action is based upon three criteria: 1) the expected net benefit, 2) the expected net preference and 3) the benefit to cost ratio. The expected optimal action should be the action with the largest expected net benefit value (algebraic sum of cost and benefit) or the largest expected net preference value or the largest benefit to cost ratio according to each criterion. In reality, the decision analysis based upon the utility theory should consider the decision maker's preference regarding the risks (e.g., risk-prone, risk-averse or risk-neutral). In this advisory mode BBN model, the expected net benefit criterion is based upon the assumption of the risk-neutral preference of the project manager so the criterion for decision making for the expected optimal action is based upon a monetary scale cost and benefit analysis. For the expected net preference criterion, the preference function would be obtained from the experts (i.e., real human project managers). The process and results of preference function assessment are discussed in a later section.

Based upon identified important factors for each work phase in Figure 3-1, the advisory mode BBNs for five different work phases have been developed as in the predictive mode case. The structures of BBNs for different project work phases are similar to each other except for considered important input factors. For example, Figure 3-9 illustrates the advisory mode BBN for the conceptual design work phase.

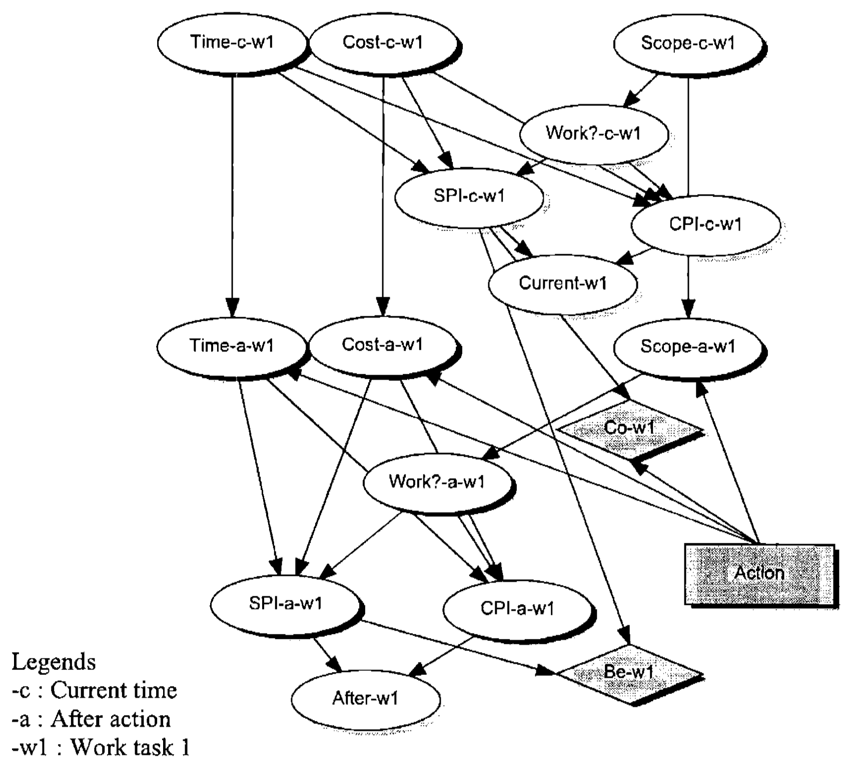


Figure 3-9. Structure of a single-work task advisory mode in the Conceptual Design Phase

3.4 Cost and benefit analysis in the BBN

3.4.1 Two types of costs and benefits

There are two types of costs and benefits that are occurring as the result of taking an action by management as shown in Figure 3-10: 1) immediate (or short-term) costs and benefits, and 2) long-term benefits (or penalty). There is certainly some immediate feedback concerning the cost of an action and some immediate mechanism in determining benefit (i.e., short term effect – post action). It is important to be able to determine immediate impact (i.e., expected immediate net benefit), which can be evaluated in terms of the shift up (or down) along the SPI curves (Earned Value Chart) and the post-action project performance state.

In addition to immediate costs and benefits, long-term benefits exist for a company such as gains from an under-spent project budget, an incentive from the project owner company, the company's improved reputation, and so on as a result of being ahead of the project schedule. However, in the case of delayed project completion, there is a cost penalty from the domino effect that originates from failure of timely achievement of deliverables, lost reputation, and so on. Those long-term benefit (or penalty) values are not considered in the immediate costs and benefits of an action taken. The project managers can think about the long-term benefit at any time of the decision making process during the project lifetime, but this long-term benefit is mainly concerned with the delay of project completion compared to the scheduled completion time. In other words, although the long-term benefit can be recognized at any time during project lifetime, the time it really occurs will be at the time of project completion. Also, the long-term benefit cannot be determined until scheduled project completion at which time the project completion status (i.e., whether or not the project is completed on time, within budget and performance limits) will be known. Example estimations of immediate costs and benefits and long-term benefit as functions of the SPI state at project completion time are illustrated in Figure 3-10.

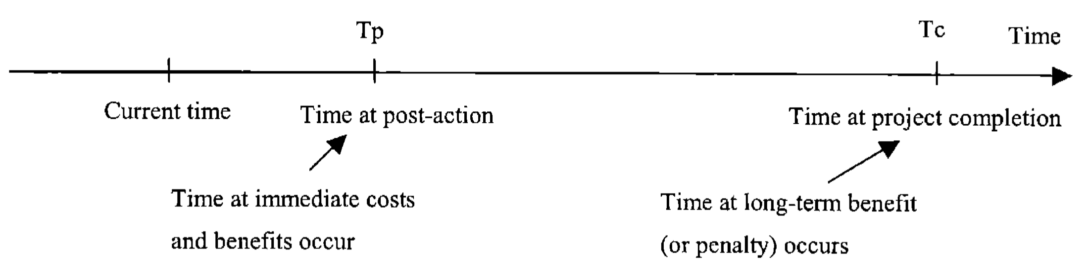


Figure 3-10. Time scale of two types of costs and benefits

Estimation of immediate costs and benefits

Suppose, the project SPI is currently running at 0.9 (slightly behind schedule) as in equation (3-4). The project management then hires an additional person (added cost). It is therefore predicted that the project SPI will be 1.0 – Case 1 or 0.95 – Case 2 within a month. The immediate benefit for hiring an additional person is that the project is back on schedule (no slippage) and new hire needs also the immediate cost. 'No action – Case 0' results in an unchanged status with no immediate cost and no immediate benefit, which would not be good in the long-term (i.e., the time when the project ends) but quite good in the short-term range (i.e., within a few months).

$$\text{Current SPI}=0.9=\text{BCWP}/\text{BCWS}=\$90{,}000/\$100{,}000 \qquad (3\text{-}4)$$

In this situation, a project manager takes the action 'Hire more people' with an estimated cost of $1,000 and period of one month, bringing the SPI to 1.0.

Case 0

If project manger takes 'No action' (Base assumption)

1) Immediate cost of this action = $ 0
2) Gross immediate benefit of this action = $ 0
3) Net immediate benefit of this action = Gross immediate benefit of this action – Immediate Cost of this action = $ 0

Case 1

After 1 month, SPI gets back to 1.0

Then the immediate part of cost and benefit would be

1) Immediate Cost of this action = $1,000
2) Gross immediate benefit of this action = BCWS-BCWP=$100,000 - $90,000=$10,000
3) Net immediate benefit of this action = $ 10,000 - $ 1,000 = $ 9,000

Case 2

After 1 month, SPI gets back to 0.95

Then the immediate part of cost and benefit would be

1) Immediate Cost of this action = $1,000
2) Gross immediate benefit of this action = 0.95*BCWS - BCWP = 0.95*$100,000 - $90,000 = $5,000
3) Net immediate benefit of this action = $ 5,000 - $ 1,000 = $ 4,000

Estimation of long-term benefit (or penalty)

It is possible to estimate the long-term benefit values if we assume to know the project performance state at the scheduled project completion time. For example, suppose that the project performance curve (i.e., SPI) shows a value of 0.85 at the scheduled project completion time, and then the project management has to spend more money to complete the project with extended (or rescheduled) project lifetime. The long-term penalty under this situation would include additional labor cost, additional material cost, lost reputation of company, and so on. In addition, the long-term penalty should include the interest and/or penalty due to delay if written as such in the contract. In summary, long-term penalty means the total amount of additional costs to the company in order to complete the project, contractual penalties and the company's lost reputation due to delay of project completion. While the other elements of additional cost are clear and tangible, the reputation loss may have ambiguous and intangible meaning. Therefore, further discussion about the meaning of company's reputation follows.

If the contracted company fails to complete the project on time, within budget and performance limits, it might result in serious damage on the company's image (i.e., company's reputation), hence customer and stockholders dissatisfaction. Then what is the meaning of reputation in the context? A brief definition of reputation can be found in Milewicz J. and Herbig P.'s paper; *"Reputation is the estimation of the consistency over time of an attribute of an entity"*. In other words, reputation is an aggregation of all previous transactions of the company over its lifetime up to the present and requires consistency of the company's actions over a prolonged time for its formation. The main contributors to reputation are the company's historic performance quality (work performed or products manufactured), credibility (whether the company can be relied upon and do what it says it will do) and integrity (the honesty of its board of directions and management staff), as perceived by potential customers. Reputation is one of the most important factors on the company's future business. For example, in the case of governmental contracting, the company faces a single customer and failure to perform successfully can be catastrophic in terms of obtaining further contracts with the government. Therefore, the term 'reputation value' can be interpreted in two ways: 1) the premium that a customer is willing to pay more because the company has higher quality, credibility and integrity compared to its competitors and 2) the future revenue due to the increased chance of more business because of the company's better image of success. Reputation loss, which is intangible, may be the largest component in the penalty suffered by a contracted company, which in most cases is due to delay in project completion.

Suppose, instead, that the SPI of the scheduled project completion time shows value of 1.1. Then some benefits to the company are gains from under-spent project budget, incentives from project owner company, improved reputation, and so on. In this case, the long-term benefit can be positive number (i.e., not penalty). The relationships for a long-term benefit (or penalty) value estimation are illustrated below in equations (3-5) and (3-6).

Case 1. SPI at scheduled project completion time is less than 1.0

Total long-term penalty value = Tangible penalty + Intangible penalty

Tangible penalty = Additional labor cost + Additional material cost + Penalty in contract

Intangible penalty = Company's reputation loss. (3-5)

Case 2. SPI at scheduled project completion time is 1.0 or greater than 1.0

Total long-term benefit value = Tangible benefit + Intangible benefit

Tangible benefit = Gains from under-spent project budget + Incentive from project owner company

Intangible benefit = Improved company's reputation. (3-6)

Once the SPI at scheduled project completion time and the components in above the equations are determined, then the long-term benefit values can be estimated as seen in Table 3-9.

Table 3-9. Example long-term benefit (or penalty) as function of SPI state at scheduled project completion time

SPI state at scheduled project completion time	0.6 ~ 0.8	0.8 ~ 1.0	1.0 ~ 1.2
Long-term benefit (or penalty) (k$)	X1	X2	X3

Note: X1 and X2 are likely to be negative (penalty) and X3 is positive (benefit)

3.4.2 Cost and benefit trees

In order to do the cost and benefit analysis in the advisory mode BBN, two things are needed: 1) input conditional probability values and 2) cost and benefit data of a corresponding scenario. The probability values of each scenario node can be computed automatically in the BBN, but the cost and benefit data should be assigned to a specific node in the advisory mode BBN.

Usually, these cost and benefit values are different from one situation to another. So the user of the advisory mode BBN should assign these cost and benefit data based upon the specific conditions. In order to estimate those values properly, the user should know the cost and benefit analysis structure and procedure running in the advisory mode BBN. In the advisory BBN for the steam generator replacement project, cost and benefit values are focused on the SPI states because of the characteristics of the project, which has a much higher priority on the time schedule than on other factors.

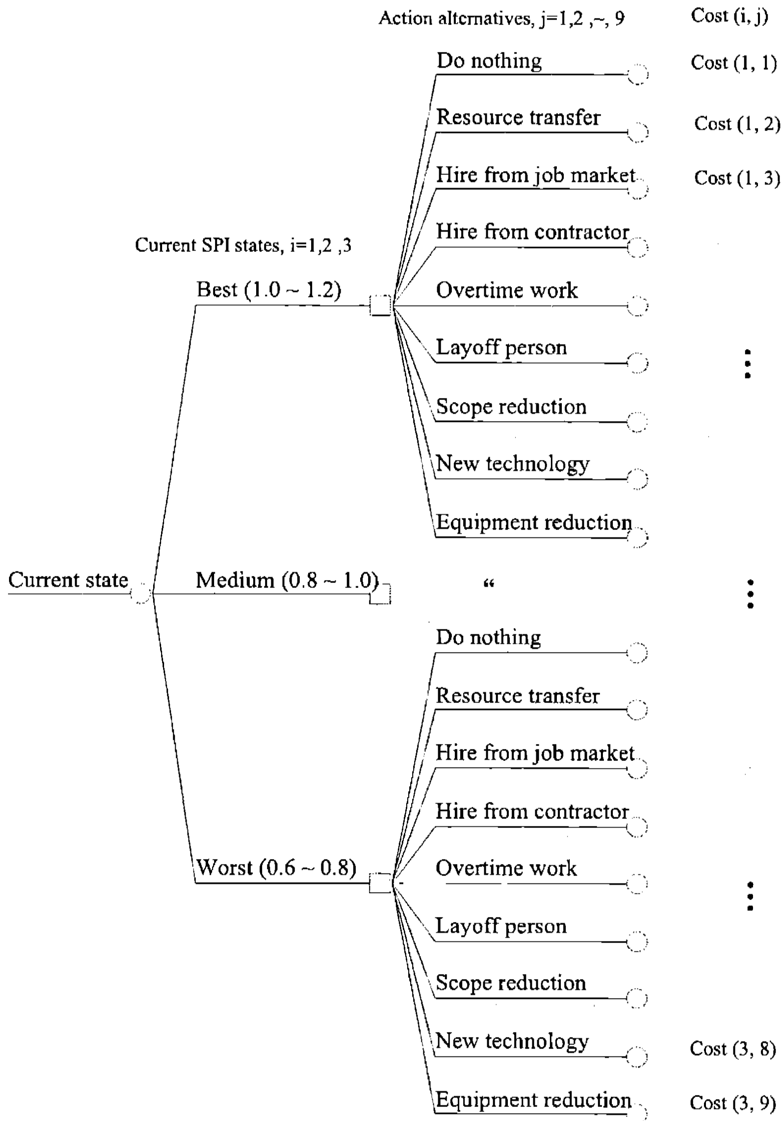


Figure 3-11. Tree for an immediate cost evaluation in the advisory mode BBN

Consider one of three current states of an SPI having nine choices of potential actions. After taking one of these nine action alternatives, there will be one of three post-action SPI states. Based upon this procedure, two trees can be drawn: a cost tree and a benefit tree. The immediate cost is believed to originate from the process of taking action but, with some action (e.g., layoff of workers), the cost may have a positive value in some cases. This is contrary to the trend of costs having negative values as is generally believed. Figure 3-11 shows 27 (three current SPI states and nine action alternatives) immediate cost values depending upon specific conditions.

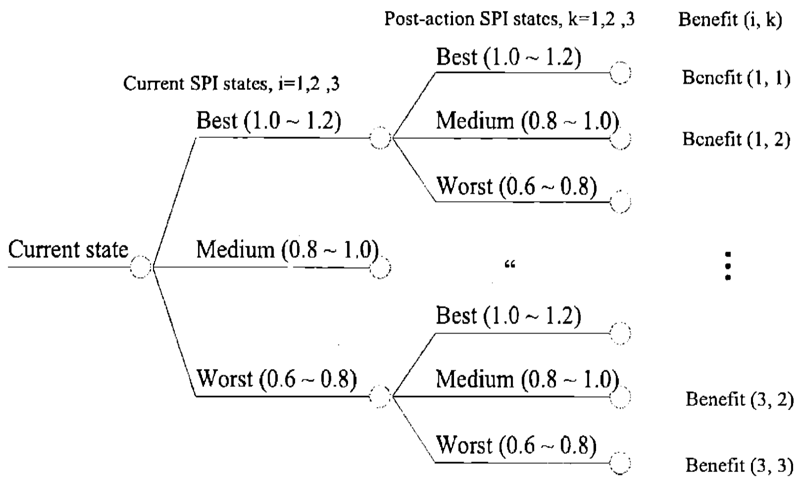


Figure 3-12. Benefit tree for an immediate benefit evaluation in the advisory mode BBN

Immediate benefits originate from the transition of the project performance status, from the current state to the short time (usually in a few months) post-action state. The project performance status may be changed into either better conditions or worse conditions after taking one action from the alternatives. Depending upon the direction of transition, these immediate benefit values can have either positive or negative values. For example, the benefit (3, 1) in Figure 3-12 can be a positive and the benefit (1, 3) can be a negative number, respectively. Figure 3-12 also shows that we have nine immediate benefit values depending upon current and post-action SPI states.

If two immediate benefit and immediate cost trees are combined, the real decision tree for immediate cost and benefit analysis can be obtained as in Figure 3-13. To obtain a good estimate in the advisory mode BBN, the user should properly assign 27 immediate cost values and nine immediate benefit values to the individual work task based upon the specific project conditions.

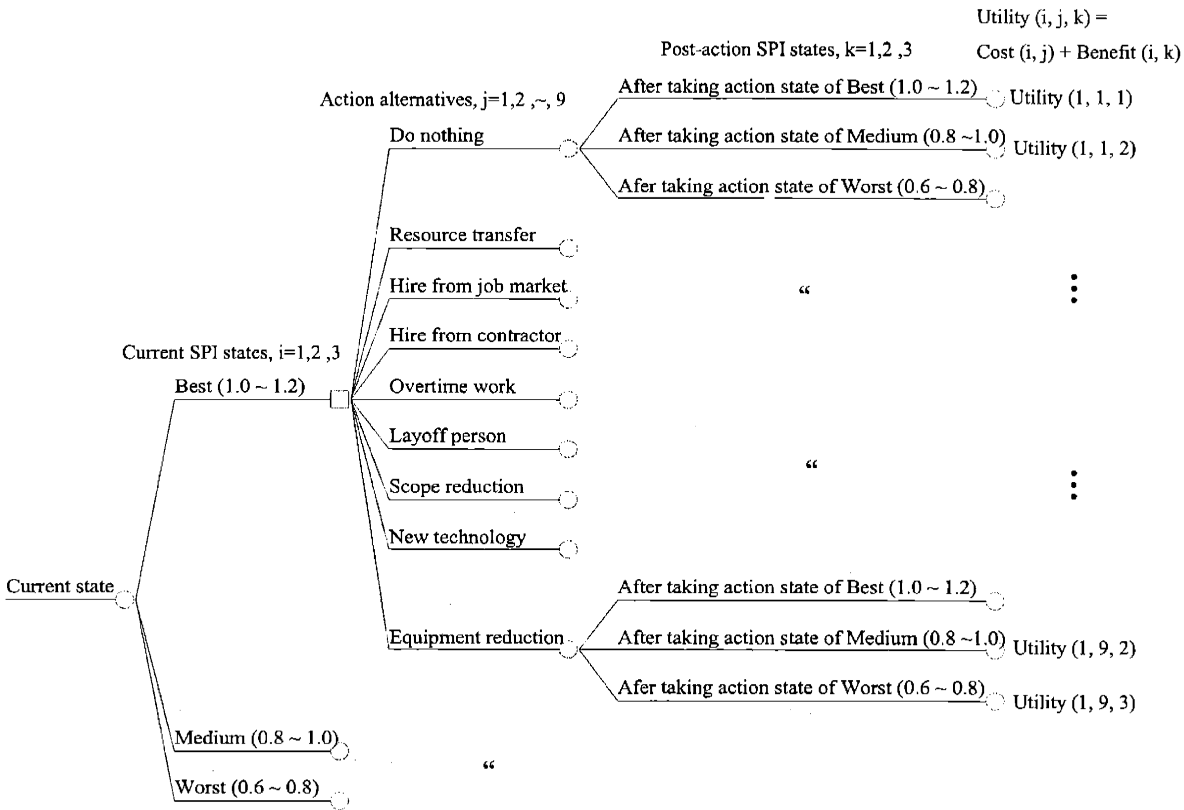


Figure 3-13. Decision tree for immediate cost and benefit in the advisory mode BBN

As explained earlier, the long-term benefit (or penalty) originates from the transition of the project performance status, from the post-action state to the state at scheduled project completion time. Like in the case of immediate costs and benefits, these values can be either positive (i.e., benefit) or negative (i.e., penalty) values. Figure 3-14 shows nine long-term benefit (or penalty) values depending upon SPI states at post-action time and at scheduled project completion time. It should be noted that there is a large uncertainty in long-term benefit evaluation since the project performance status may be changed with a large uncertainty due to a large span of time. Therefore, the best way to include such big uncertainties into the analysis is to estimate the long-term benefit values as probability distributions. The estimation of long-term benefit values is discussed in a later section.

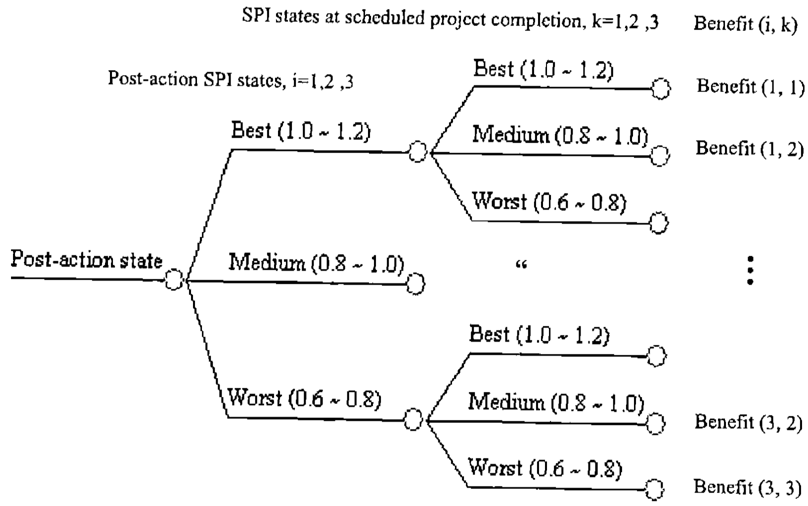


Figure 3-14. Benefit tree for a long-term benefit (or penalty) in the advisory mode BBN

3.5 Grouping work packages

The BBN approach has an inherent limitation as briefly described in Section 2.3.2. The number of conditional probability values needed to represent the relationships between factors in the domain grows exponentially when the number of factors and states increases. For example, consider that factor (A) has 10 parent factors (B, C, D, E, F, G, H, I, J, K) and they all have three states, then the number of probability values needed to define this single child factor becomes 3^{11} = 177,147, as shown in equation (3-7), a nearly impossible number to evaluate.

$$\text{Number of } P(A \mid B,C,D,E,F,G,H,I,J,K) = 3\times3\times3\times3\times3\times3\times3\times3\times3\times3\times3 = 3^{11} . \quad (3\text{-}7)$$

Consequently, a very large amount of computer memory is needed in order to store those probability values and to compute the proper procedures. For example, 708,588 bytes of memory are needed to store a condition probability table for this one single child factor above since four bytes are needed for each probability value. Furthermore, the connectivity of the graph of the BBN also needs large storage requirements of the junction tree. The junction tree is the secondary computational structure, which is used for performing the probabilistic inference. In summary, a very large amount of built-in computer memory is needed in order to compute a BBN model that has a large sized complex domain problem.

In current BBNs, there exists a limitation on the number of work tasks and future steps that can be treated in a single model due to the inherent limitations mentioned above. The 3-work tasks model is the maximum-sized BBN that can be used at the current time. Initially, an attempt was made to represent a single-work package with a single-work task in the BBN. With the current model, this is possible only when three work packages are performing at the same time. In reality, however, the number of work package performing simultaneously ranges approximately from 7 to 15. So it is impossible to represent a single-work package with a single-work task in the current BBN models and hence, single-work task BBNs should represent a number of work packages that have a similar characteristic. Therefore a reasonable way must be found to represent whole-work packages that are performing at the same time with current 3-work tasks model. One possible solution to this problem is classifying a number of work packages into three different groups, as the following method shows:

1. Select sample work packages being performed at the same time from project schedule
2. Assign the conditional probability value set to each work package by relevant experts
3. Classify work packages with similar conditional probability values into the same group
4. Identify similar characteristics of the work packages in the same group
5. For members of the same group, assign averaged conditional probability values.

Considering the Final Report for the St. Lucie Steam Generator Replacement Project, a number of work packages being conducted at the same time can be identified. The following work packages were performed during the period of the outage work phase, 12/1 ~ 12/10. It should be noted that the period 12/1 ~ 12/10 is not the entire outage work phase or the duration of each work package. This period was simply chosen as the time period for this example analysis. The following 12 work packages are assumed to have the same structure of the BBN model since they are all in the outage work phase. The tasks performed at same time are the following:

1. Install Snubber System & Upper Laterial Restrain
2. RC (Reactor Coolant) Pipe Installation
3. Main Steam Pipe Installation
4. Feedwater Pipe Installation
5. Install Blowdown Modification
6. Install Primary Side Instrument Pipe
7. Install Secondary Side Instrument Pipe
8. Install Insulation
9. Install Pipe Installation
10. Install Construction Hatch Steel Cap
11. Install MSRR (Main Steam Rupture Restraints)
12. Remove Temporary Gantry Crane.

As results of the grouping approach using the above procedure, the following three groups are identified as shown in Table 3-10 and group-representing unique conditional probability values are obtained through iterations with domain experts.

Table 3-10. Members of the grouped work packages of the St. Lucie SGR project

Group	Title of work package
Group 1 (Most difficult group)	Install Snubber system & upper laterial restrain
	Install insulation
	RC (Reactor Coolant) pipe installation
	Install construction hatch steel cap
	Install MSRR (Main Steam Rupture Restraints)
Group 2 (Medium difficult group)	Main steam pipe installation
	Feedwater pipe installation
	Install blowdown modification
	Remove temporary gantry crane
Group 3 (Least difficult group)	Install primary side instrument pipe
	Install secondary side instrument pipe
	Install pipe insulation

The members of Group 1 are found to be by far the most difficult to implement in performance and, for each of these, there are many unknown factors that could affect the construction phase of the work. In considering the St. Lucie Nuclear Power Plant Steam Generator Replacement Project schedule, each individual member of Group 1 would appear on the critical path. Therefore the work packages of Group 1 have the characteristics of both being difficult to implement and being critical for overall project performance. Group 2 modifications are much easier to implement from cost, schedule and complexity points of view and Group 3 is even easier. The average conditional probability values are estimated from several probability value sets in individual work groups that were obtained from domain experts for each work package (i.e., five conditional probability value sets for the most difficult group. Four for the medium and three for the least) and are assigned to the members of individual work groups in the BBN model for the overall project level.

It should be noted that not every work phase has all three work group characteristics. For example, the conceptual design work phase has only two work group characteristics: 1) medium and 2) least difficult. The most difficult group should usually relate with craft & construction works during the site & craft mobilization and outage work phases. The medium and least difficult groups are related with design engineering & later filed supports so these two groups can be applied from the earliest conceptual design work phase to the last outage work phase. This is summarized in Table 3-11.

Table 3-11. Work groups in each work phase

Work phase	Applied work groups
Conceptual design	Medium and least difficult groups
Detailed design	Medium and least difficult groups
Work package development	Medium and least difficult groups
Site & craft mobilization	Most, medium and least difficult groups
Outage	Most, medium and least difficult groups

3.6 BBN modeling for overall project level

Based upon the BBN model structure for a single-work task in Section 3.3 and the results of the grouping approach in Section 3.4, the predictive and advisory modes BBN models for the overall project level have been developed. Detailed explanations about the overall project level BBNs are described in following sections.

3.6.1 Predictive mode BBN for single-work phase with 3-time step model

It is assumed that the structure for an individual work group in the BBN model for overall project level is very similar to that of the single-work task level in Section 3.3. The domain experts confirm this assumption to be reasonable. Therefore, the structure of a three-work group BBN model is assumed to be a collection of three identical single-work group models as shown in Figure 3-22. There are three columns for the individual work groups, representing the most difficult, medium difficult and the least difficult to implement, which are determined using the group approach results in Section 3.5. Anther column, the overall project performance, is composed of two factors for overall project level, overall SPI and overall CPI. Overall project level SPI and CPI can be inferred from three SPI and CPI states of an individual work group level. The predictive mode BBN for overall project level can give the future project performance probability distributions of both the single-work group level and overall project level, given current evidence.

Like in the single-work task level BBN case, the overall project level predictive mode BBNs for five different phases have been developed based upon identified important factors for each of the work phases in Figure 3-1. The structure of different work phase BBNs is similar to each other except for considered important input factors. For example, Figure 3-24 illustrates the overall project level predictive BBN in the conceptual design work phase.

As discussed in Section 2.3.3, the BBN approach has an inherent limitation: the number of conditional probability values needed for describing the strength of our belief on dependent relationships among variables increases exponentially as the number of variables grows and hence, a large amount of computer memory and a very fast computational speed are required. Due to these reasons, there was a limitation on the number of future time steps (i.e., 3-time step model was maximum size) that the predictive mode BBN could handle. Furthermore, the conditional probability sets for different time horizons (i.e., from 1 month to 12 months in the future – 12 different conditional probability sets for single variable) were required to deal with up to 12 months in the future as illustrated in Figure 3-15. As a result, the large memory space needed for storing this large number of conditional probability sets causes the computational speed to be significantly slow. Therefore, it was necessary to develop a new algorithm in order to overcome this computational speed problem. The new algorithm developed for the predictive mode BBN will be discussed in the next section.

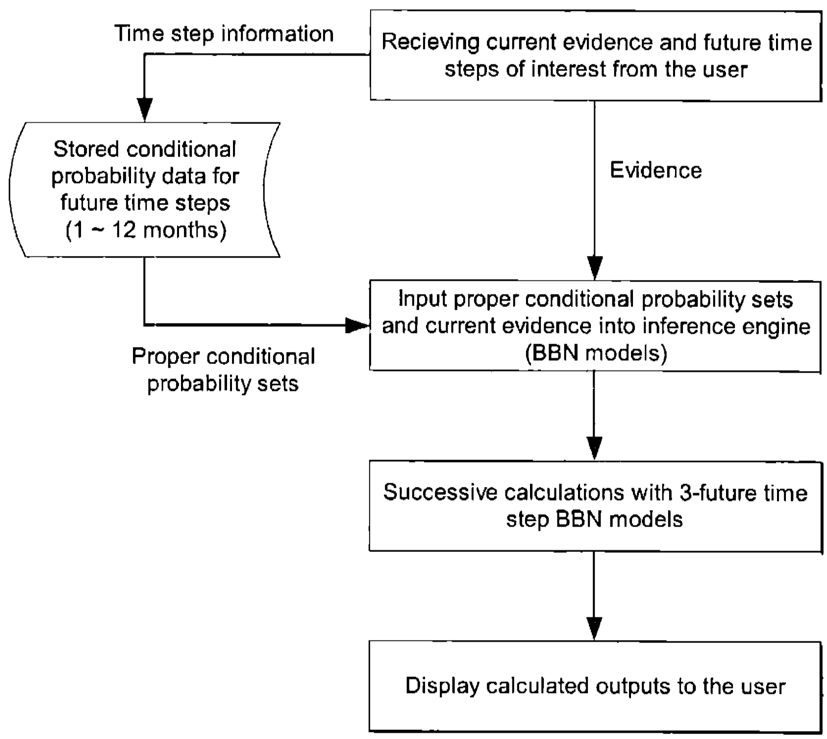


Figure 3-15. Calculation algorithm with 3-time step predictive mode BBN

3.6.2 Predictive mode BBN for single-work phase with 1-time step model

Due to the computational speed problem discussed in Section 3.6.1, new algorithm to enhance the speed has been developed as described in Figure 3-16. The main feature of the new algorithm is to repeat the one future-time prediction calculation with repeatedly updated evidence with one time-step model until it reaches the largest future time-step of interest. In the new algorithm, the 1-month future project performance predicted with current evidence is converted into new current evidence in the next time step and then, the 2-month future project performance can be calculated with new current evidence (i.e., 1-month future project performance). This process repeats until the future prediction reaches the largest time step defined by the user; for example, if the user defined the largest future time wanted as 10 months future then the prediction process is repeated ten times with the current evidence updated nine times. The 1-time step model does not need to store 12 different conditional probability sets and hence, it does not need a large size memory to store a large number of probability sets. As a result, the computational time is significantly enhanced with the help of a large size memory allocated for calculation, not for just storing data. For example, while it took 2 ~ 3 minutes to compute one case of prediction with the previous 3-time step model, only 3 ~ 5 seconds are needed for the same case of prediction with the newly developed 1-time step algorithm. The 1-time step model for the predictive mode BBNs are shown in Figures 3-23 and 3-25. The advisory system in this work employs the newly developed 1-time step algorithm for predictive mode BBNs.

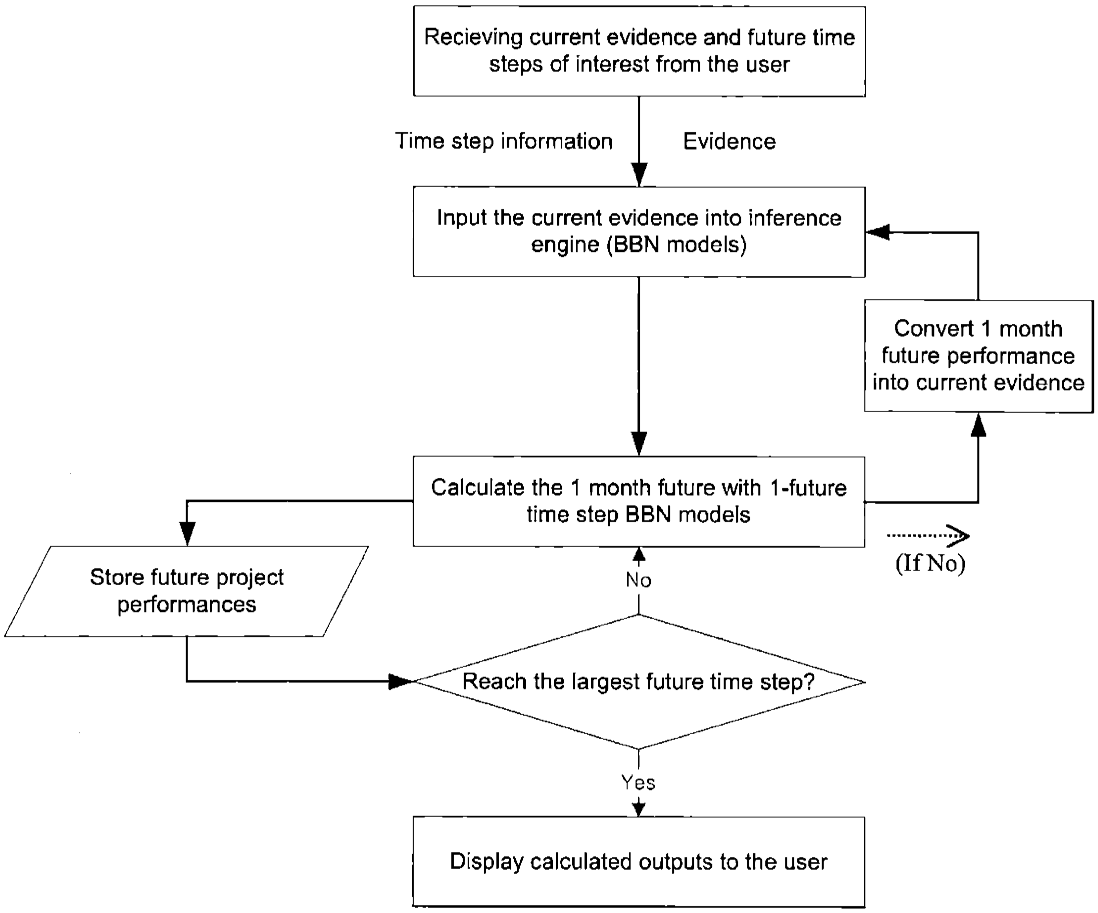


Figure 3-16. Calculation algorithm with 1-time step predictive mode BBN

3.6.3 Predictive mode BBN for project lifetime

Another predictive mode BBN for whole project lifetime has been developed, which is different from the previous predictive mode BBN models. While the predictive mode BBN models in Sections 3.6.1 and 3.6.2 are for project performance prediction within single-work phase (i.e., five different models for five different work phases), the predictive mode BBN described in this section is for prediction of project performances at the scheduled project completion time. In addition, it should be noted that the BBN model for project lifetime in this section does not have three different work group characteristics (i.e., most, medium and least difficult to implement groups) as used in the previous predictive mode for a single-work phase. The overall project level SPI and CPI are evaluated from the important input factors, and the overall profit in EAC (Estimate At Completion) can be estimated from overall SPI and CPI states as in Figure 3-28. The three outputs of SPI, CPI and profitability of overall project level in this model are for the scheduled project completion time, given the current evidence, not for one month or two months in the future as in the other predictive mode BBNs. It should also be noted that these prediction values are under the assumption that there will be no intervening action by management from the current time to project completion time. In this model, two additional input factors are considered as seen in Figure 3-28: 1) Change-XX - Is there any change from the original schedule? and 2) Cl_Agree-XX? - If there is any change, do we get the client's agreement on this change? The client's agreement is important in change order because there would be a schedule adjustment, if we could get the client's agreement. Therefore there would be no impact on project performance (e.g., SPI, CPI and profit). However, if the client does not agree on a change order, then there would be negative impact on SPI, CPI and profit.

3.6.4 Advisory mode BBN

From the preliminary analysis of sensitivity and discussion with domain experts, it is recognized that the long-term benefit plays the most important role in determining optimal action among alternatives. Therefore, for identifying optimal action more accurately and reliably, the long-term benefit should be incorporated into the cost-benefit analysis. As the first step to incorporate the long-term benefit, it should be noted that the times at which two different benefits would occur are not same as illustrated in Figure 3-10, where immediate cost and benefit occur at time of post-action and long-term benefit (or penalty) occurs at time of project completion. Therefore, it is proposed that the advisory mode of BBN should be developed to consider two different time values of expected immediate net benefits and expected long-term benefit in one mode. The advisory mode BBN developed for incorporating the long-term benefit into the expected net benefit analysis would follow the steps in the flowchart as shown in Figure 3-17. Detailed descriptions of each step can be found subsequent to that figure. It is believed that the optimal action identified based upon two expected net benefits can give more reliable and accurate advice to the project management than by only the expected immediate net benefit.

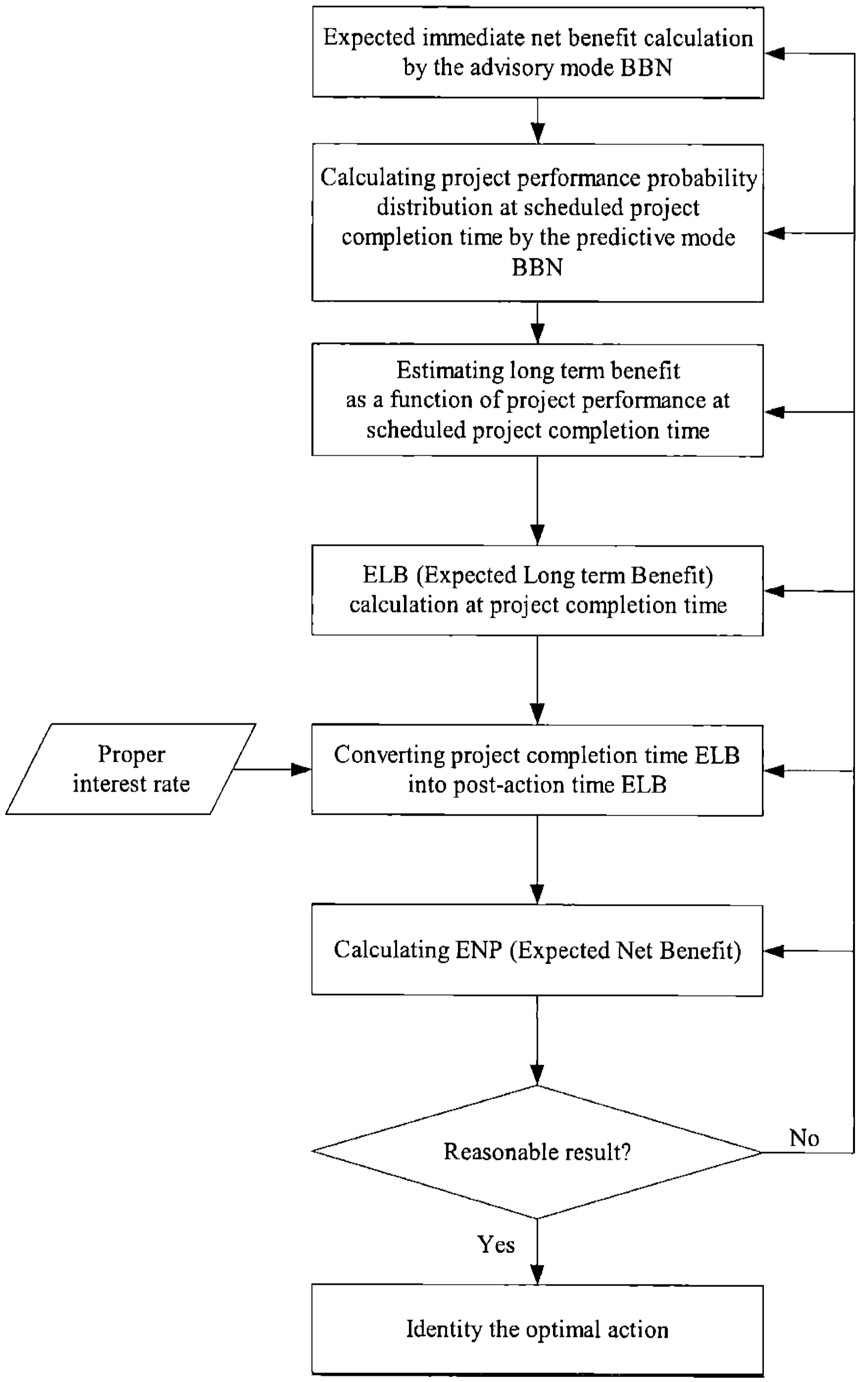


Figure 3-17. Flowchart for newly proposed advisory mode BBN

Step1 – Expected immediate net benefit calculation by the advisory mode BBN

The expected immediate net benefit at time of post-action can be calculated automatically using the BBN advisory mode with the immediate cost and benefit information of an action, which can be estimated from the SPI curve change from the pre-action and post-action states. Also the project performance states probability distributions after taking an action are calculated using the advisory mode BBN for SPI, CPI and the important input factors as well.

Step2 – Project performance probability distribution predictions at scheduled project completion time by the predictive mode BBN

Based upon the identified post-action project performance states (i.e., using the post-action project performance state as current evidence into the predictive mode BBN), the project performance probability distributions at scheduled project completion time can be predicted using the predictive mode BBNs.

Step 3 – Estimating the long-term benefit

With the results of the predictive mode BBNs from step 2 above (i.e., the project performance probability distributions at scheduled project completion time), the expected long-term benefit at project completion time can be estimated if the long-term benefit values as function of the SPI state at that time could be obtained. Estimating the long-term benefit is very difficult during the project work period, and nearly impossible in some cases, because the long-term benefit has so many factors and large uncertainties affecting it. The only time when the estimation of the long-term benefit is possible is at the time of scheduled project completion (i.e., the time when the final project performance is known). Therefore, it is believed that once the prediction values of the project performance status at scheduled completion time are known, then it is not so difficult to estimate the long-term benefit values as a function of the SPI state at scheduled project completion time as illustrated in Table 3-12 and Figure 3-18.

Table 3-12. Example long-term benefit as function of SPI state at scheduled project completion time

SPI state at project completion time	0.6 ~ 0.8	0.8 ~ 1.0	1.0 ~ 1.2
Long-term benefit (k$)	X1	X2	X3

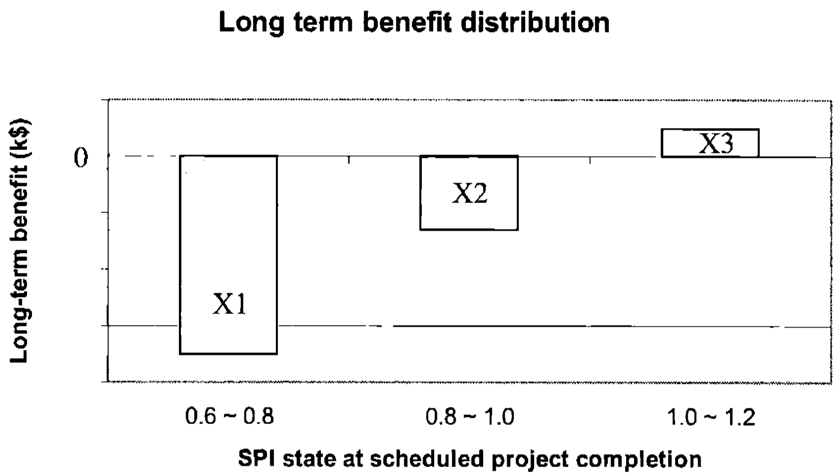
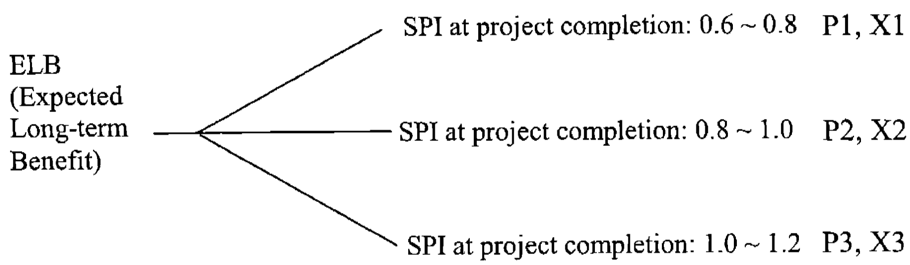


Figure 3-18. Example long-term benefit as function of SPI at scheduled project completion

<u>Step 4 – Calculation of ELB (Expected Long-term Benefit) at scheduled project completion time</u>

Once the long-term benefit values as a function of scheduled project completion time SPI states and the predictions of the SPI state probability distribution at scheduled project completion time are known, then the ELB (Expected Long-term Benefit (or Penalty)) can be calculated as illustrated in Figure 3-19 and Equation 3-8. It should be noted that the scheduled project completion time SPI state probability distribution (i.e., Pi in Figure 3-19) is automatically calculated by the predictive mode BBN, given the evidence of post-action states of actions, and the long-term benefit values as a function of scheduled project completion time SPI states (i.e., Xi in Figure 3-19) should be given by the users (or experts).



where
Pi : SPI state probability value of project performance prediction from the predictive mode BBNs
Xi : Long-term benefit value corresponding SPI state

Figure 3-19. Tree for long-term benefit calculation

$$ELB = \sum_{i=1}^{3} P_i * X_i = P_1 * X_1 + P_2 * X_2 + P_3 * X_3 \qquad (3\text{-}8)$$

As mentioned in step 3, however, the long-term benefit values have large uncertainties. Therefore, the best way to include such large uncertainties in the analysis is to estimate the long-term benefit values as probability distributions either in the form of a continuous probability distribution (probability density function; pdf) or as discrete probability distribution (probability mass function; pmf). Probability distribution estimation would also reduce difficulties and errors in the long-term benefit values rather than using point values. Once the probability distributions for long-term benefit values are estimated, there would be three different probability distributions: three probability distributions for X1, X2 and X3 in Table 3-12 are shown in Figure 3-20 as example continuous probability distributions.

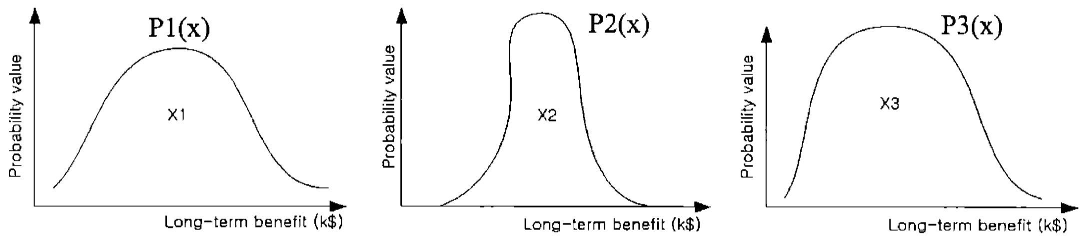


Figure 3-20. Example continuous probability distributions for long-term benefit values

Then calculate the output probability distribution (i.e., the probability distribution for *ELB* in Equation 3-6) as a function of the basic component random variables (i.e., X1, X2 and X3) since each of these three variables has its own probability distributions. However, the calculation of output probability distributions from the probability distributions of input component variables is not an easy process. Even though a general approach for this process has been developed, it is not very useful in practice and will not be presented here. For example, in the case of a linear combination of normal distribution variables, the output probability distribution can be computed theoretically. However, this is of very little use in practical problems.

Instead of the theoretical approach, the numerical approach is more widely used in practical areas. In physical problems, there are analytical expressions that are very complex and the input variables may follow any probability distributions. In many cases, there are no analytical expressions for the desired output, but rather, computer programs that can produce the output of interest. In these cases, the output probability distribution can be produced by a random sampling technique from input probability distributions. This approach is the numerical methods for output probability distribution production. One of the widely used numerical approaches is 'Monte Carlo Simulation'. Using this numerical approach on computer, the probability distribution of output variable is calculated without large difficulties in the case of continuous probability distributions.

In this analysis, these probability distributions are estimated in the form of discrete functions (probability mass functions). The current version of BBN models cannot handle the continuous probability distributions. Therefore, in order to communicate with BBN models, the continuous probability distributions for long-term benefit values cannot be used. In addition, for a practical reason, three discrete probability distributions with three values in each distribution are estimated as illustrated in Figure 3-21. In the case of three probability distributions for input long-term benefit (i.e., one pmf for X1, one pmf for X2 and one pmf for X3) and three values in each probability distribution, there are 27 (=3×3×3) combination output values in the resultant probability distributions (i.e., 27 ELBs in Equation 3-6 with 27 corresponding probability values). If the number of values in each probability distribution increases, then the number of expected long-term benefit values in the output distributions would grow exponentially (e.g., 64 = 4×4×4). This rapid growth will result in a big burden to computation time and hence, money.

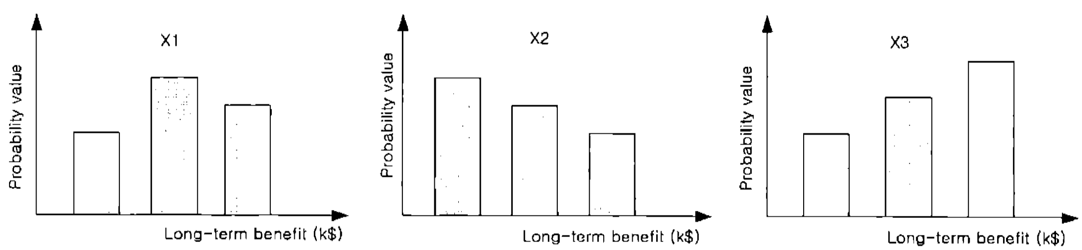


Figure 3-21. Example discrete probability distributions for long-term benefit values

In order to compare among action alternatives, a single expected long-term benefit value for each action alternative (i.e., single value ELB like in Equation 3-8) is required. In the discrete case with 27 output values (i.e., 27 ELBs from Equation 3-8 with 27 corresponding probability values), the single value ELB can be estimated with following equation (3-9).

$$ELB = \sum_{i=1}^{27} P_i * ELB_i = P_1 * ELB_1 + P_2 * ELB_2 + \cdots + P_{26} * ELB_{26} + P_{27} * ELB_{27}. \quad (3\text{-}9)$$

where

ELB = Single value of Expected Long-term Benefit at scheduled project completion time

ELB_i = 27 output Expected Long-term Benefits from equation (3-8)

P_i = 27 probability values corresponding ELB_i

Step 5 – Converting the ELB at scheduled project completion time into at post-action time

At this step, the expected long-term benefit value at the scheduled project completion time should be modified into a value for post-action time (or vice versa), taking into account interest and inflation during the period since two benefit values are needed for different time points. The proper interest rate should be selected, in order to match the one used in that project scheduling frame, from two kinds of interest rates: 1) constant interest rate or 2) market interest rate. After choosing the interest rate, the expected long-term benefit at the scheduled project completion time can be converted into the one at another time using the expression in equation (3-10).

$$ELB_p = \frac{ELB}{(1+i)^{T_c - T_p}}. \tag{3-10}$$

where

ELB = Expected Long-term Benefit at scheduled project completion time

ELB_p = Expected Long-term Benefit at post-action time

i = Interest rate

Tc = Time at scheduled project completion

Tp = Time at post-action

Step 6 – Calculation of Expected net benefit

After converting the expected long-term benefit into post-action time, the expected net benefit can be calculated from two benefits: 1) expected immediate net benefit from step 1 and 2) expected long-term benefit from step 5. It should be noted that we could estimate the expected net benefit in two ways: 1) expected net benefit at post-action time and 2) expected net benefit at scheduled project completion time. Here, the post-action time is selected because project managers usually prefer to make timely decisions on the net benefit in the near future. The expected net benefit of an action can be calculated using equation (3-11).

$$ENB = ENB_i + ELB_p \tag{3-11}$$

where

ENB = Expected Net Benefit

ENBi = Immediate Expected Net Benefit from immediate cost and benefit

ELBp = Expected Long-term Benefit at post-action time

Step 7 – Identifying the optimal action

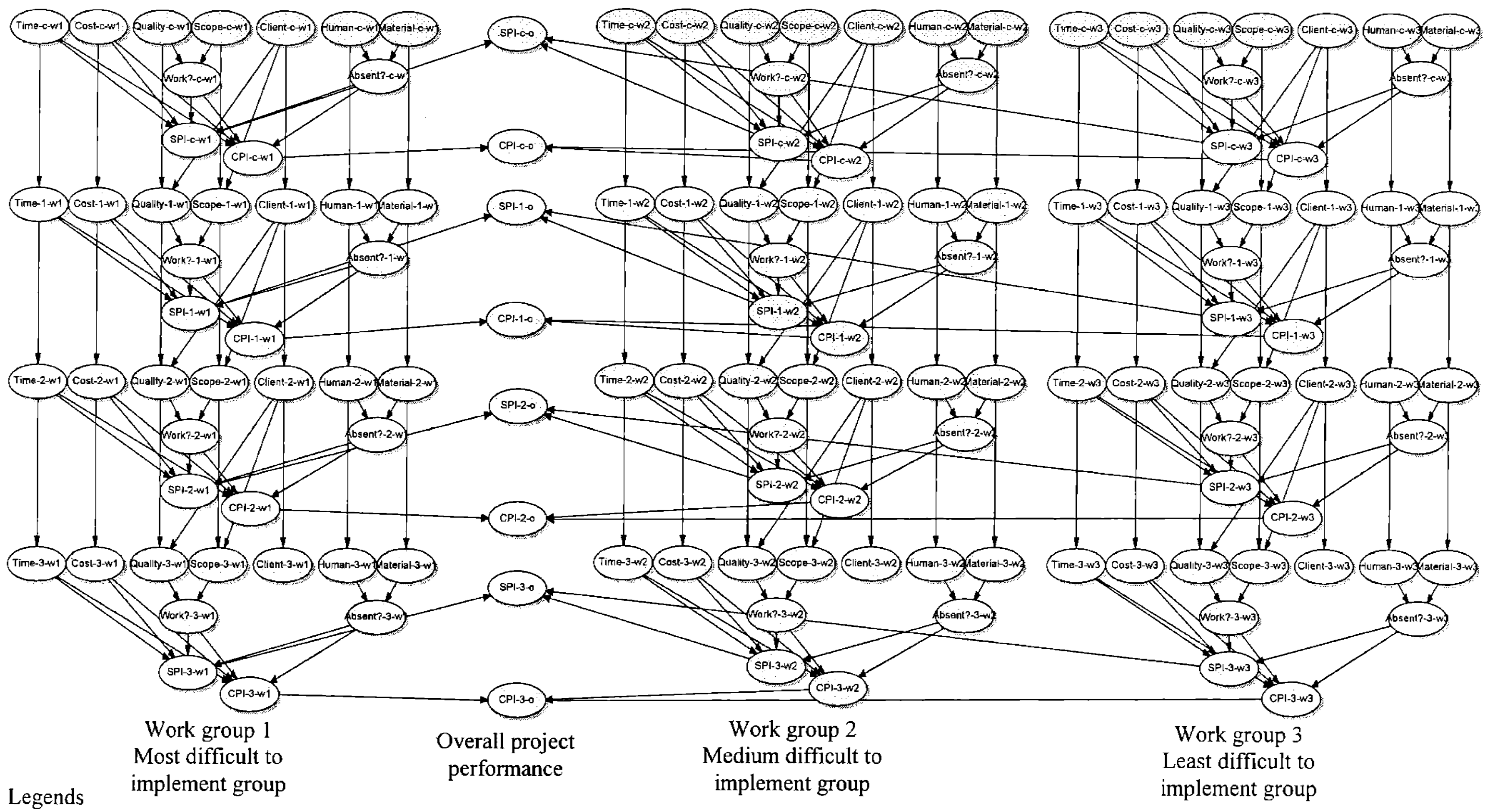
After calculation of the expected net benefit value for each action alternative, the optimal action under the current situation can be identified through comparison of these expected net benefit values. Under the assumption of risk-neutral preference by the project manager, the optimal one is the action with the largest expected net benefit.

With this approach, both the expected net benefit from immediate cost and benefit and the long-term benefit are included in the analysis. The optimal action identified based upon this approach can give more reliable and accurate advice to the project manager rather than by only the expected immediate net benefit.

Structure of advisory mode BBN models for single-work phase

The overall project level advisory mode BBN models are composed of two elements as illustrated in Figures 3-26 (for optimizing action) and 3-28 (for predicting the project performance at scheduled project completion time) for all seven important input factors (i.e., for later two work phases – site & craft mobilization and outage work phases). Based upon the identified important factors for each work phase in Figure 3-1, the overall project level advisory mode BBNs for five different work phases have been developed like in the single-work task level BBNs. The structures of BBNs for different work phases are similar to each other except for the important input factors considered. For example, Figure 3-27 illustrates the overall project level advisory mode BBN models for the conceptual design work phase that has only three important input factors (time, cost and scope). Three categories of work groups have the same group characteristics as those in the predictive mode BBN, based upon how difficult to implement it is in the project performance.

In this overall project level advisory mode BBN, the expected optimal action can be identified among alternatives in both the individual work group level and the overall project level based upon three criteria discussed in the previous section: 1) the largest expected net benefit, 2) the largest expected preference and 3) the largest benefit to cost ratio. Three expected optimal actions for an individual work group level are identified first, and then an optimal action for overall project level is obtained from the actions classified in Table 3-8. To find the overall project level optimal action, the global optimization value is computed for an individual work group level, and then the overall optimal action group name can be identified from the set of corresponding action titles of an individual work group level.



Legends
-c : Current time, -1 : 1st time step future, -2 : 2nd time step future, -3 : 3rd time step future
-w1 : Work group 1 , -w2 : Work group 1 , -w3 : Work group 1
-o : Overall project level

Figure 3-22. Structure of 3-time step, overall project level predictive mode with seven important input factors

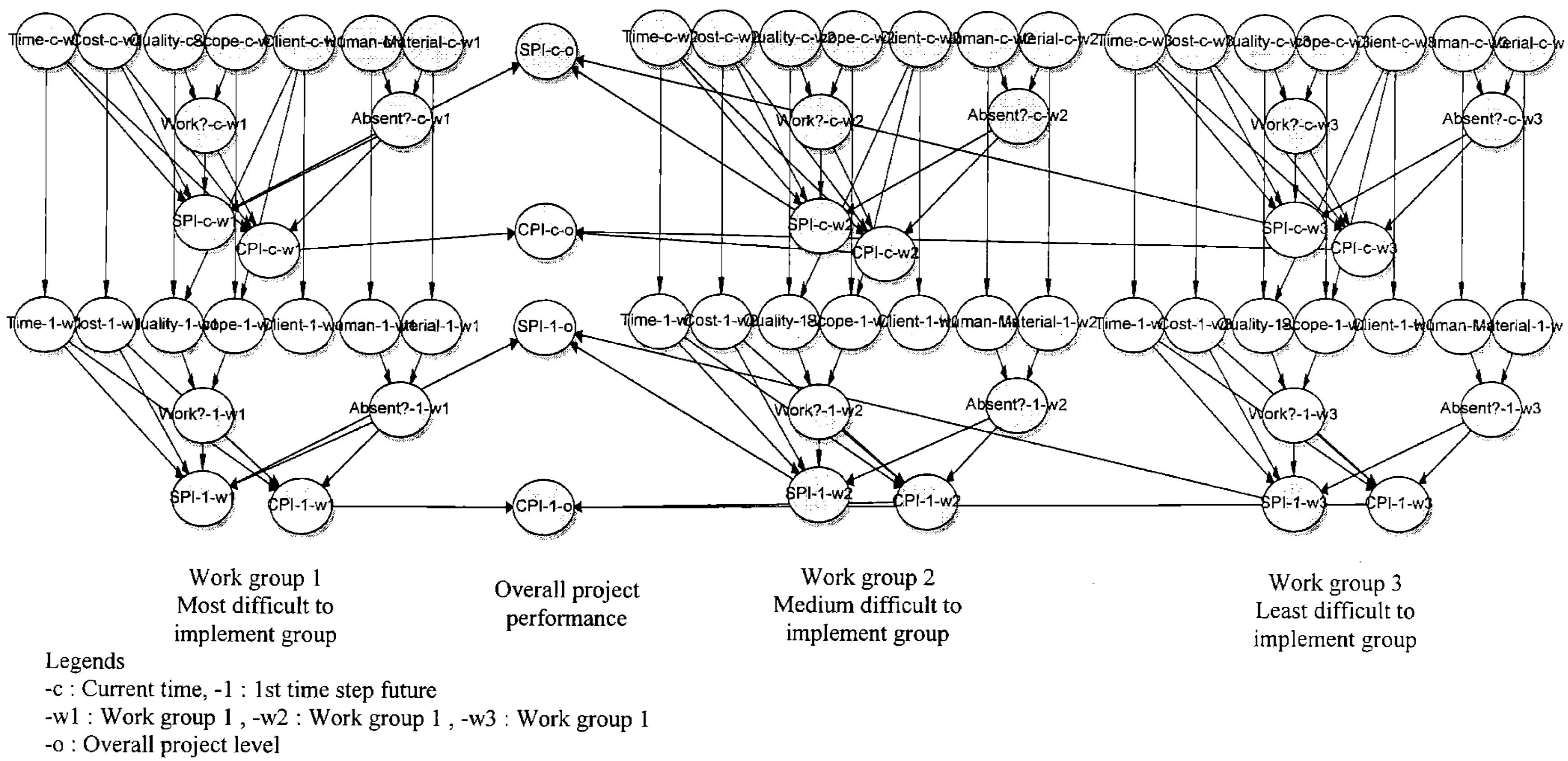
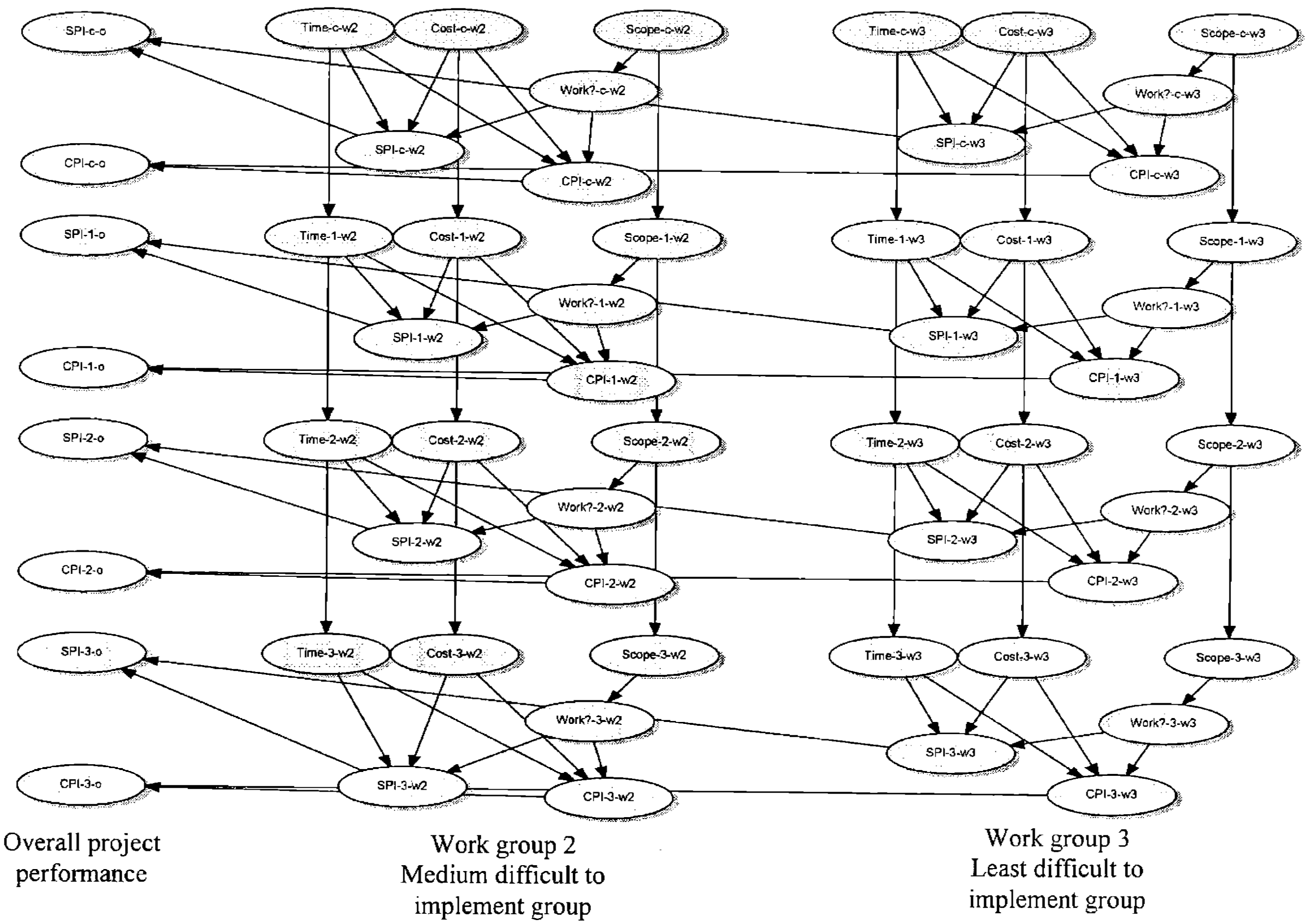
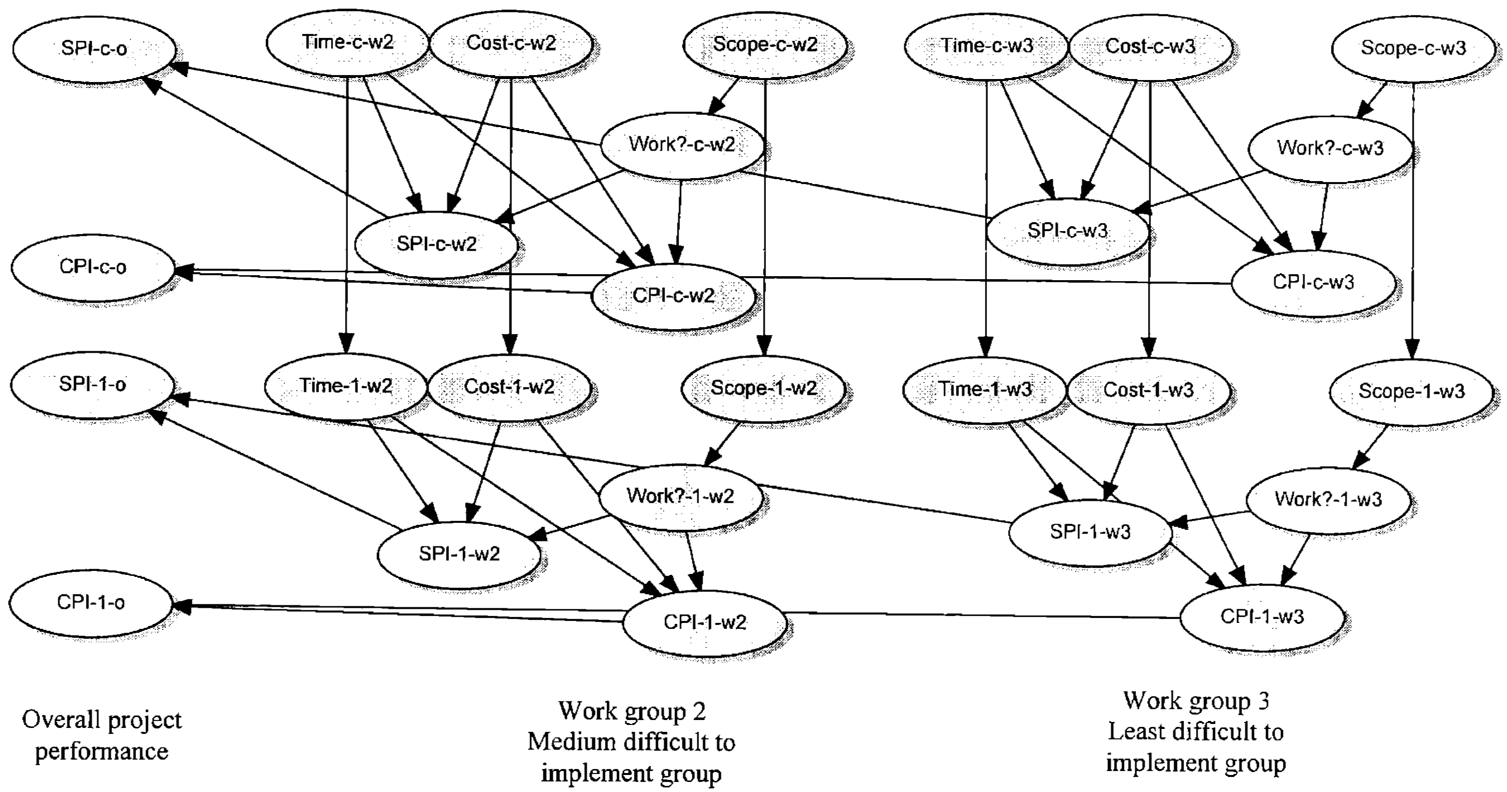


Figure 3-23. Structure of 1-time step, overall project level predictive mode with seven important input factors



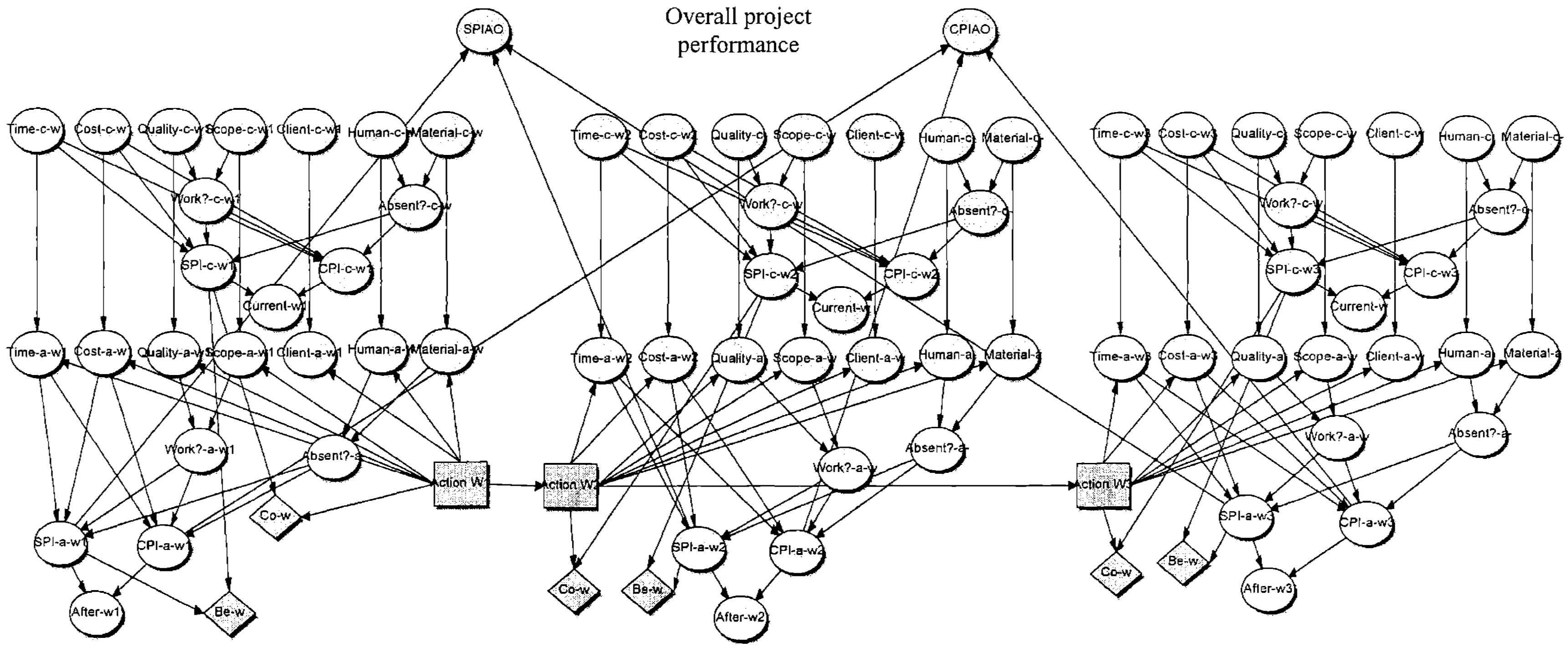
Legends
-c : Current time, -1 : 1st time step future, -2 : 2nd time step future, -3 : 3rd time step future
-w2 : Work group 2 , -w3 : Work group 3
-o : Overall project level

Figure 3-24. Structure of 3-time step, overall project level predictive mode in the Conceptual Design work phase



Legends
-c : Current time, -1 : 1st time step future
-w2 : Work group 2 , -w3 : Work group 3
-o : Overall project level

Figure 3-25. Structure of 1-time step, overall project level predictive mode in the Conceptual Design work phase



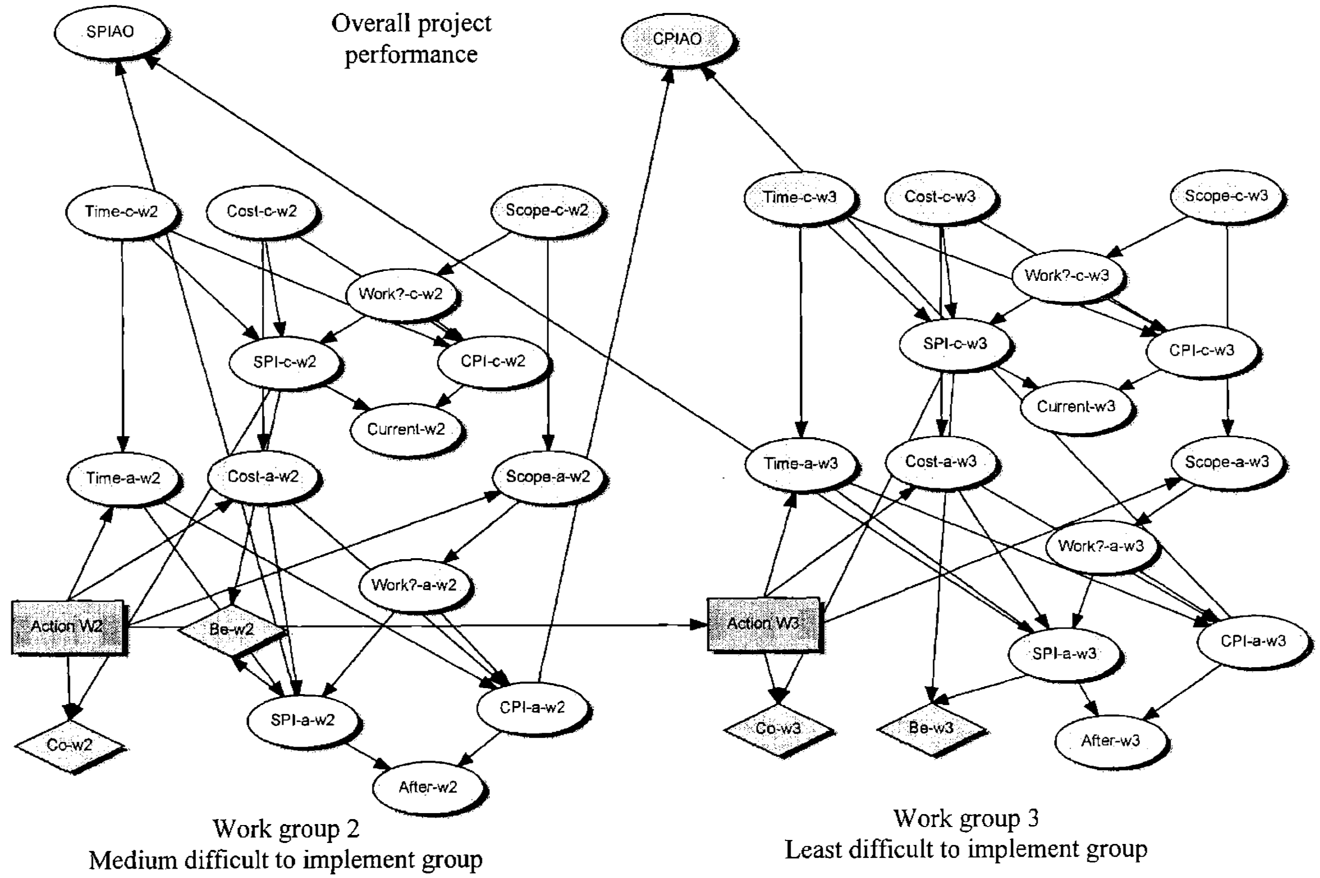
Work group 1
Most difficult to implement group

Work group 2
Medium difficult to implement group

Work group 3
Least difficult to implement group

Legends
-c : Current time, -a : After action, -o : Overall project level
-w1 : Work group 1 , -w2 : Work group 1 , -w3 : Work group 1

Figure 3-26. Structure of overall project level advisory mode with seven important input factors



Legends
-c : Current time, -a : After action, -o : Overall project level
-w2 : Work group 2 , -w3 : Work group 3

Figure 3-27. Structure of overall project level advisory mode in the Conceptual Design work phase

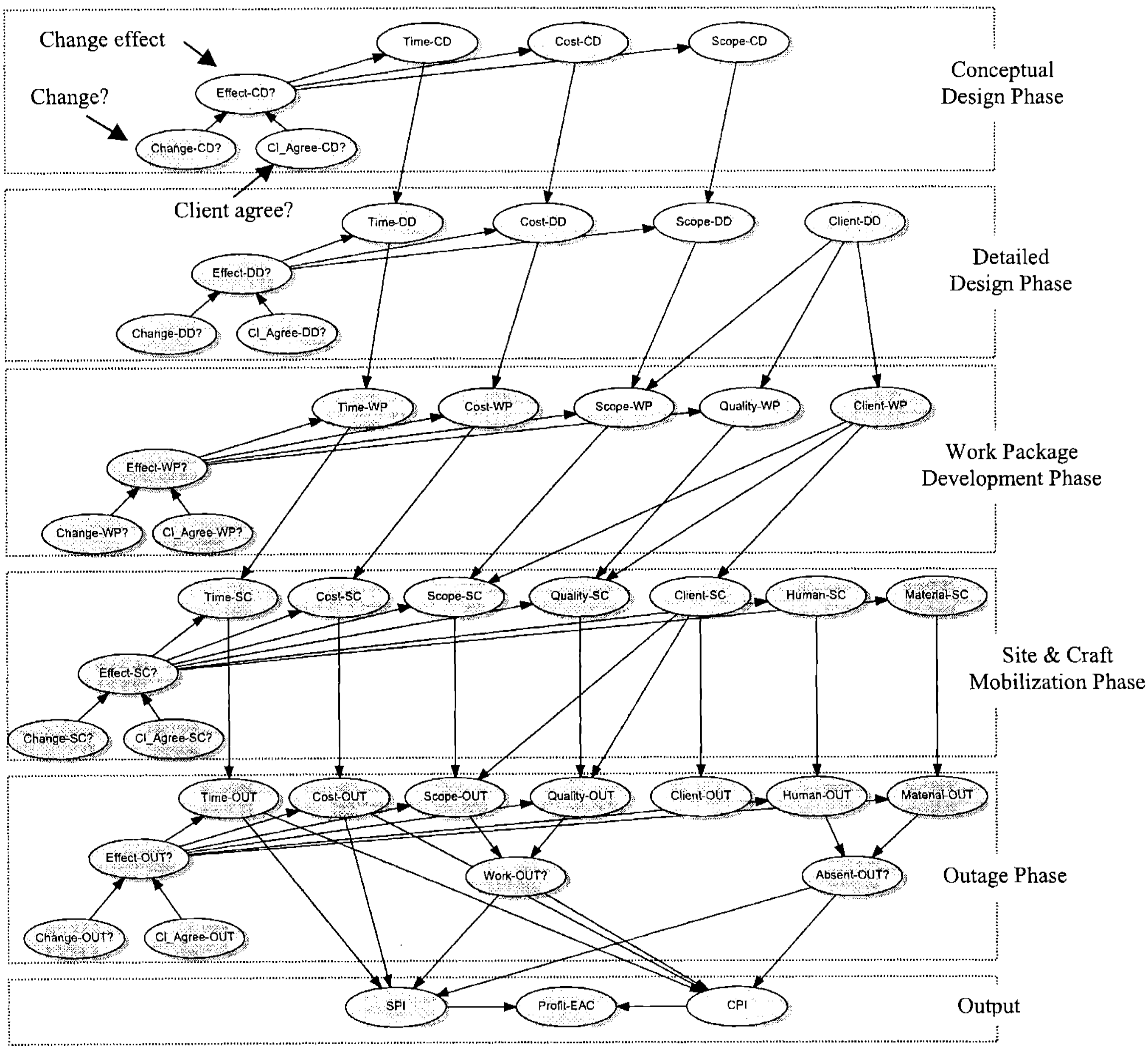


Figure 3-28. Structure of overall project level predictive mode for project lifetime

CAHPTER 4.
DEVELOPMENT of INTERFACE PROGRAM

Finding the specific factors and putting evidence to them and finding corresponding updated outputs may be cumbersome tasks because there are many factors in different BBN models for different work phases. In order to reduce this inconvenience, an interface program between users and inference engine models, BBN models that are running in the background for probabilistic reasoning, has been developed using the Visual Basic language.

4.1 Predictive mode BBN interface program

Figure 4-1 shows a layout of the predictive mode BBN interface program. The window is split into two sections: the upper section for evidence input for three work groups in each work phase and the lower section for corresponding output project performance probability distributions for specified output factors. In the input section, there are nine option buttons for each of nine factors (time, cost, scope, quality, client satisfaction, human resource, material resource, group SPI and group CPI) for entering the current evidence input since this window is for the Site & Craft Mobilization work phase. The ranges (or states) for each evidence factor were defined in Section 3.1. The window for the site & craft mobilization work phase can be switched into any another work phase using 'Predictive Mode' commands at the top of window. In addition, it can be changed into an advisory mode BBN window using the command 'Advisory Mode', which is next to 'Predictive Mode'. Below the option buttons for entering the evidence, there are two buttons to update and initialize. These buttons are for updating the project performance probability distributions in the output section after entering evidence for the current project status and for initializing the updated probability distribution outputs before entering more new evidence (i.e., back to the prior probability distributions). These two commands, update and initialize, can be found in the command line 'Action' at the top of window, also.

The output results section has two parts: future overall project level SPI performance prediction and future overall project CPI performance prediction probability distributions, as shown in Figure 4-1. In the currently developed interface program window for the predictive mode, the future time predictions are up to three time steps in the future since there is no enough space for displaying more future time prediction results. Since the conditional probability values between current and next time steps are for 1-month future prediction, the output section is labeled using a future-month scale. If the user changes the time steps (i.e., currently 1-, 2- and 3-months future in Figure 4-1) into another time scale (i.e., for example 4-, 6- and 9-months future), then the interface program switches the results for 1-, 2- and 3-future months into corresponding results for the changed time scale (i.e., 4-, 6- and 9-future months) by clicking the command 'Change Time Step' in 'Action' at the top of window.

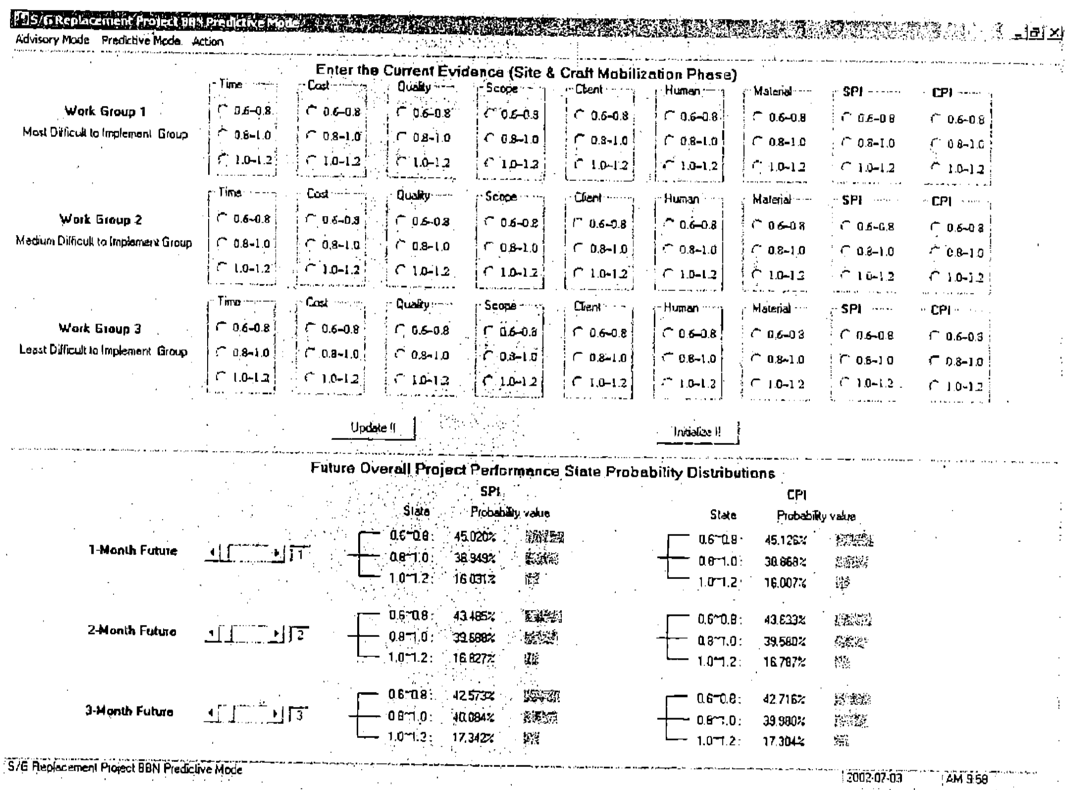


Figure 4-1. Predictive mode interface program for single work phase with prior probability distributions

There are two kind of probability distributions in the interface program for the predictive mode and the advisory mode: 1) prior probability distribution – belief in hypothesis based upon current knowledge accumulated up to now, without any new evidence and 2) posterior (updated) probability distribution – updated with new current evidence representing current situations from prior probability distribution, using the Bayes' updating theorem. Figure 4-1 illustrates the green colored prior probability distributions on project performance in the Site & Craft Mobilization work phase. The output overall project performances of SPI and CPI in Figure 4-2 represent the red colored updated (or posterior) probability distributions with the assigned current evidence that is shown in upper part of window. In the case in Figure 4-2, it shows that all input variables lie in their best state (i.e., 1.0 ~ 1.2) among three states (i.e., 0.6 ~ 0.8, 0.8 ~ 1.0 and 1.0 ~ 1.2). When the updated project performances in Figure 4-2 are compared to the prior project performances in Figure 4-1, they show that all project performances indices (i.e., SPI and CPI) represent larger possibility in better states due to the best evidence.

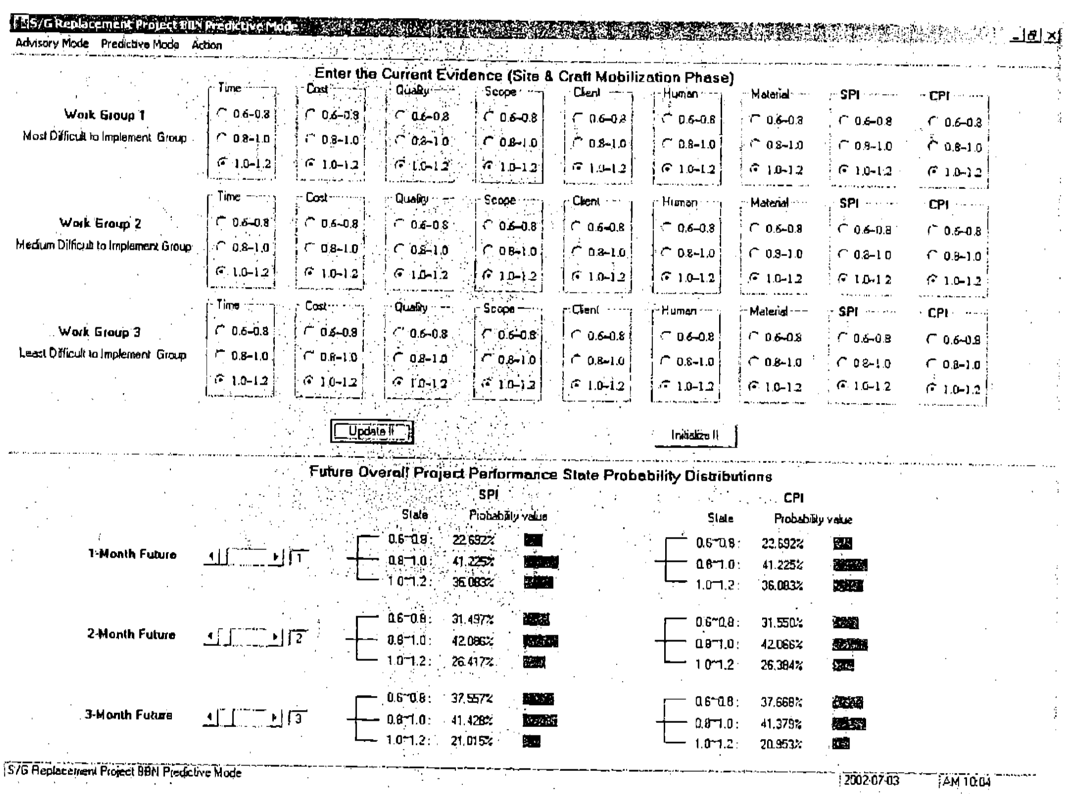


Figure 4-2. Predictive mode interface program for single work phase with updated probability distributions

Figure 4-3 shows another predictive mode interface program window for project lifetime and overall project level performance predictions. It should be noted that the predictive mode window in Figures 4-1 and 4-2 is for predictions for future times within a single-work phase but the predictive mode window in Figure 4-3 is for prediction of project performances at the scheduled project completion time. Two additional input factors to the seven important factors are considered in each work phase as seen in Figure 4-3: 1) Change? - Is there any change from the original schedule within the work phase? and 2) Client agree? - If there is any change, do we get the client's agreement on this change? As discussed in Section 3.6.3, the client's agreement to change orders is important since there would be a schedule adjustment based upon the client's agreement. As a result of schedule adjustment, there would be no impact on the project performance (e.g., SPI, CPI and Profitability). However, if the client does not agree on a change, then there would be a negative impact on SPI, CPI and Profitability.

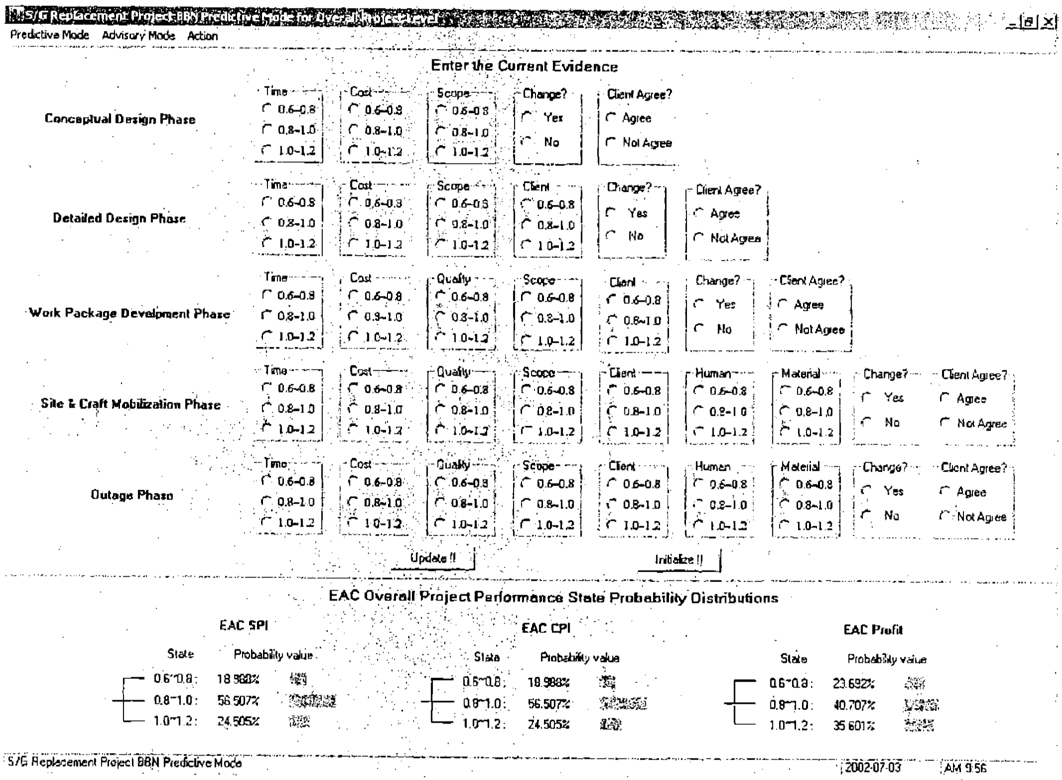


Figure 4-3. Predictive mode interface program for project lifetime and overall project level with prior probability distributions

The same approach concerning the two kinds of probabilities (i.e., prior and posterior) is employed here – green colored prior probability distributions and red colored posterior probability distributions. Figure 4-4 summarizes the information flow in the predictive mode interface program.

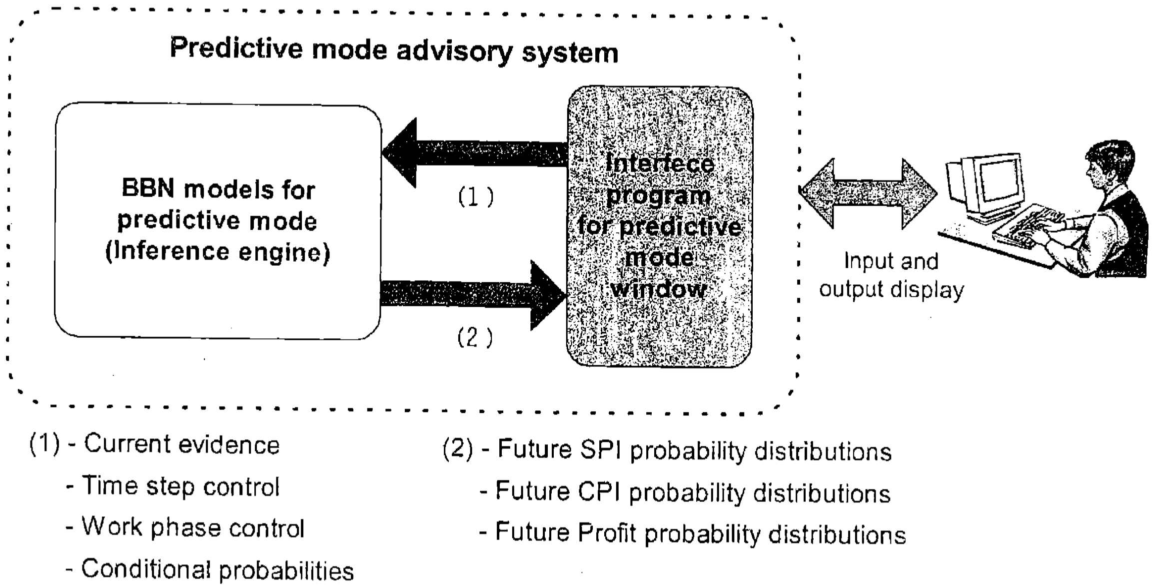


Figure 4-4. Information flow of the predictive mode advisory system

4.2 Advisory mode BBN interface program

The layout of the advisory mode BBN interface program is shown in Figure 4-5. Like in the predictive mode case, the window is divided into two sections: the upper section for entering the current evidence input for three work groups in each work phase and the lower section for corresponding project performance probability distributions for the output factors and the expected optimal actions for both three work group levels and overall project level. Nine option buttons for each of nine input factors (time, cost, scope, quality, client satisfaction, human resource, material resource, group SPI and CPI) exist for evidence input for each individual work group in upper part since this window is for the site & craft mobilization work phase. Also like the predictive mode interface program, the window for the current work phase can be switched into any other work phase using commands at the top of window. It can be changed into the predictive mode BBN window using the command 'Predictive Mode', which is next to 'Advisory Mode'. Below the option button for evidence input, there are two buttons to update and initialize. Usage of these two buttons is the same as in the predictive mode case. Unlike the predictive mode window, the output results section has three parts: post-action SPI, CPI performance probability distributions and the expected optimal action advice for the individual work group level and overall project level. It should be noted that the post-action SPI and CPI probability distributions are the states after taking corresponding optimal actions that are advised in the advisory mode BBN. In addition, the advisory mode interface program can show us the project performance probability distributions at scheduled project completion time by clicking 'Show project completion probability' in 'Show' command.

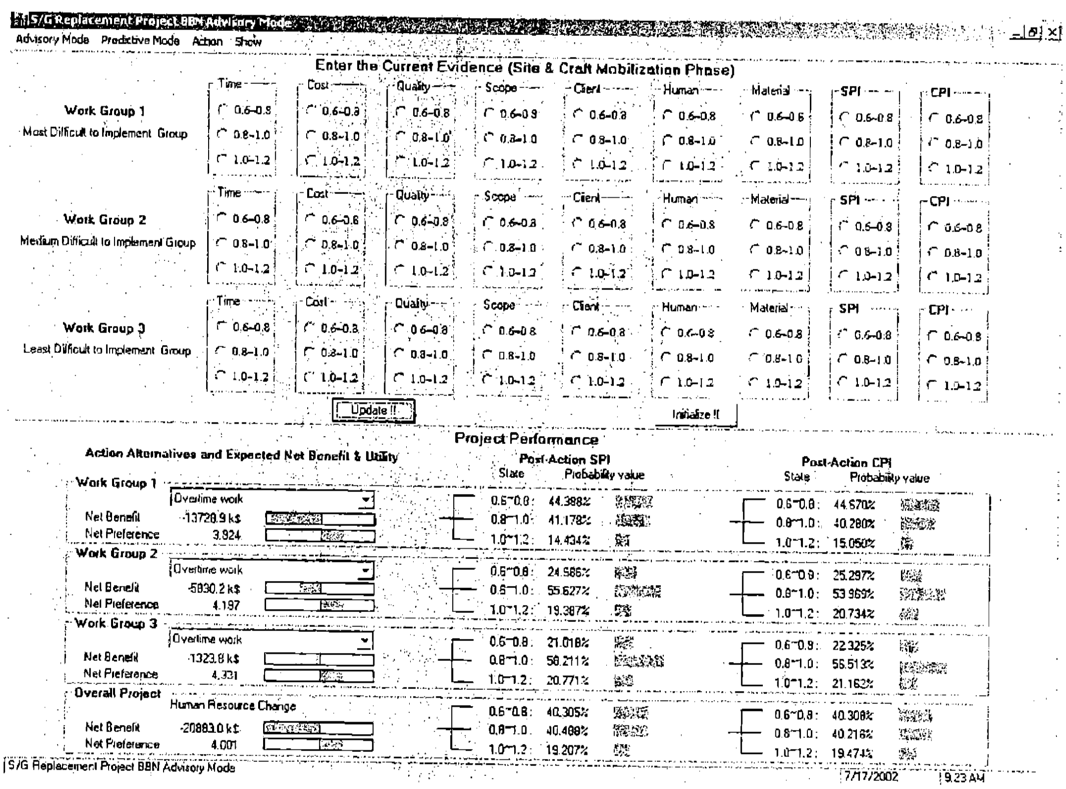
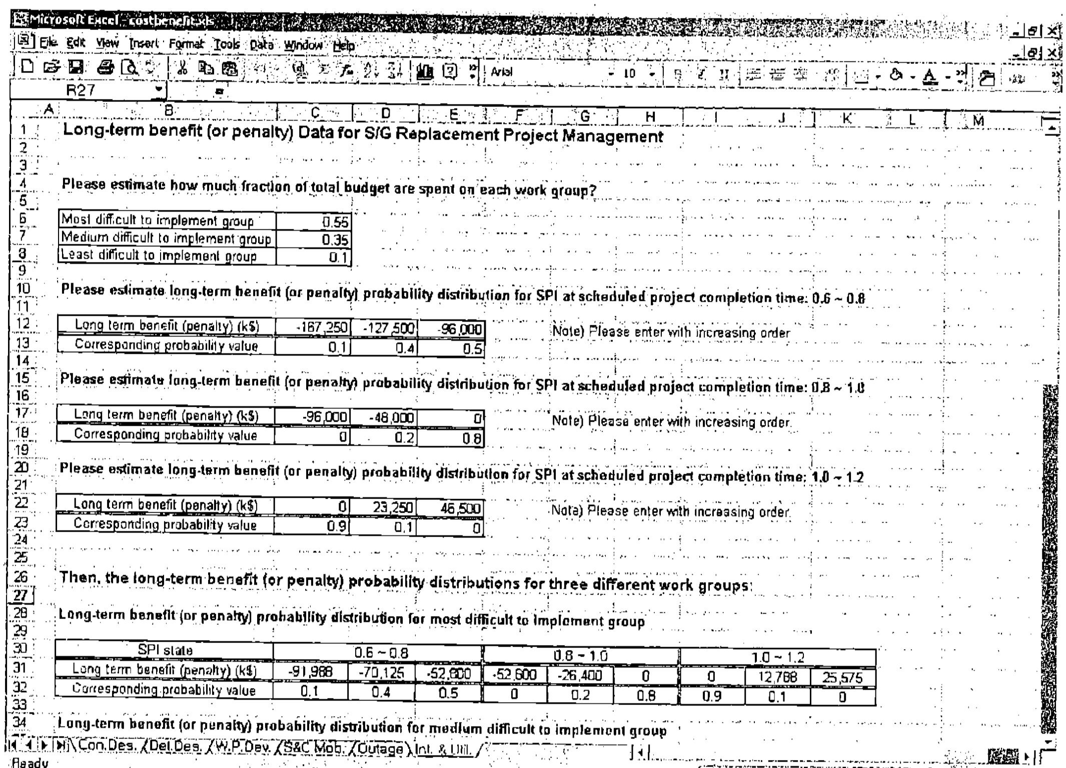


Figure 4-5. Advisory mode interface program for single work phase with prior probability distributions

As mentioned in Section 3.4, the user should assign both the immediate cost and benefit values and the long-term benefit (or penalty) under the specific project performance state into the BBN advisory mode. The interface program provides the function to do this as illustrated in Figure 4-6. The advisory mode BBN reads data from the specified Excel file, and then updates the computation results using the new cost and benefit values.



Microsoft Excel - costbenefit.xls

Long-term benefit (or penalty) Data for S/G Replacement Project Management

Please estimate how much fraction of total budget are spent on each work group?

Most difficult to implement group	0.55
Medium difficult to implement group	0.35
Least difficult to implement group	0.1

Please estimate long-term benefit (or penalty) probability distribution for SPI at scheduled project completion time: 0.6 ~ 0.8

Long term benefit (penalty) (k$)	-167,250	-127,500	-96,000
Corresponding probability value	0.1	0.4	0.5

Note) Please enter with increasing order

Please estimate long-term benefit (or penalty) probability distribution for SPI at scheduled project completion time: 0.8 ~ 1.0

Long term benefit (penalty) (k$)	-96,000	-48,000	0
Corresponding probability value	0	0.2	0.8

Note) Please enter with increasing order.

Please estimate long-term benefit (or penalty) probability distribution for SPI at scheduled project completion time: 1.0 ~ 1.2

Long term benefit (penalty) (k$)	0	23,250	46,500
Corresponding probability value	0.9	0.1	0

Note) Please enter with increasing order.

Then, the long-term benefit (or penalty) probability distributions for three different work groups:

Long-term benefit (or penalty) probability distribution for most difficult to implement group

SPI state	0.6 ~ 0.8			0.8 ~ 1.0			1.0 ~ 1.2		
Long term benefit (penalty) (k$)	-91,988	-70,125	-52,800	-52,800	-26,400	0	0	12,788	25,575
Corresponding probability value	0.1	0.4	0.5	0	0.2	0.8	0.9	0.1	0

Long-term benefit (or penalty) probability distribution for medium difficult to implement group

Con.Des. / Del.Des. / W.P.Dev. / S&C Mob. / Outage / Int. & Util.

Ready

Figure 4-6. Excel file for entering cost and benefit values for the advisory mode BBN

The user may want to know more information on the expected net benefit, the expected preference results and the post-action state probability distributions for all action alternatives rather than those of the advised expected optimal action only. For this purpose, the advisory mode BBN interface program provides the whole picture of the cost and benefit analysis and expected preference calculation results for all action alternatives. In order to do that, the user clicks the command 'Show' and then selects the group of interest. Then the interface program opens a new window and displays the whole analysis results in descending order from the optimal one, as shown in Figure 4-7.

Like in the main advisory mode window, the post-action project performances can be changed into the project performance predictions at the schedule project completion time. For the two kinds of probabilities (i.e., prior and posterior), the same scheme is used in the advisory mode case – green colored prior probability distributions and red colored posterior probability distributions.

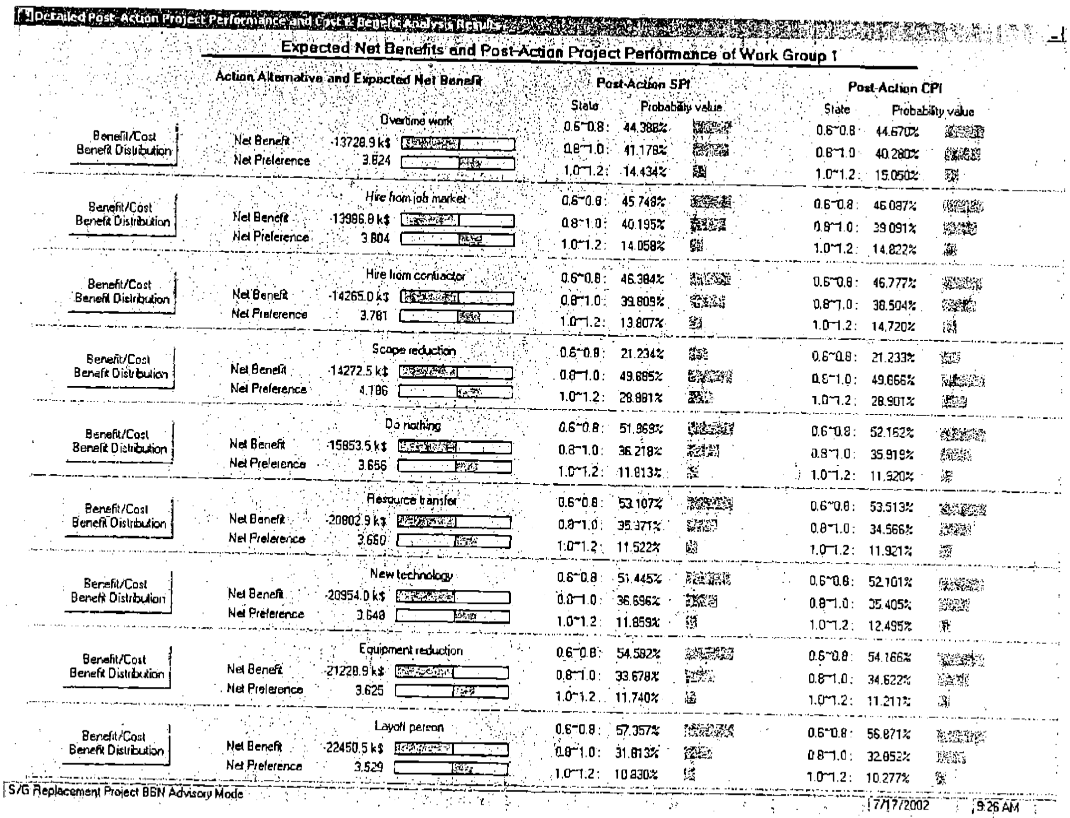


Figure 4-7. Advisory mode interface window for all action alternatives

Figure 4-8 shows the advisory mode window for detailed information of individual action alternative. This new window is opened by clicking the left button 'Benefit/Cost, Benefit Distribution', of each action row as shown in Figure 4-7. The detailed information window is composed of four parts: 1) Expected net benefit to cost ratio, 2) Net benefit (Immediate + Long-term) probability distribution, 3) Net benefit distribution description, which is the amount and probability values of 27 net benefit values in distribution and 4) Summary of the immediate expected net benefit, expected long-term benefit and total expected net benefit. Among three criteria to determine the optimal action, while the expected net benefit and the expected preference appear in the main advisory mode interface mode window, the third one, 'Benefit to cost ratio', can be seen only in the detailed information window. It should be noted that the 'Benefit to cost ratio' criterion cannot be applied to the 'Do nothing' action since it doesn't have any immediate action cost and hence, the value of benefit to cost ratio goes to infinity.

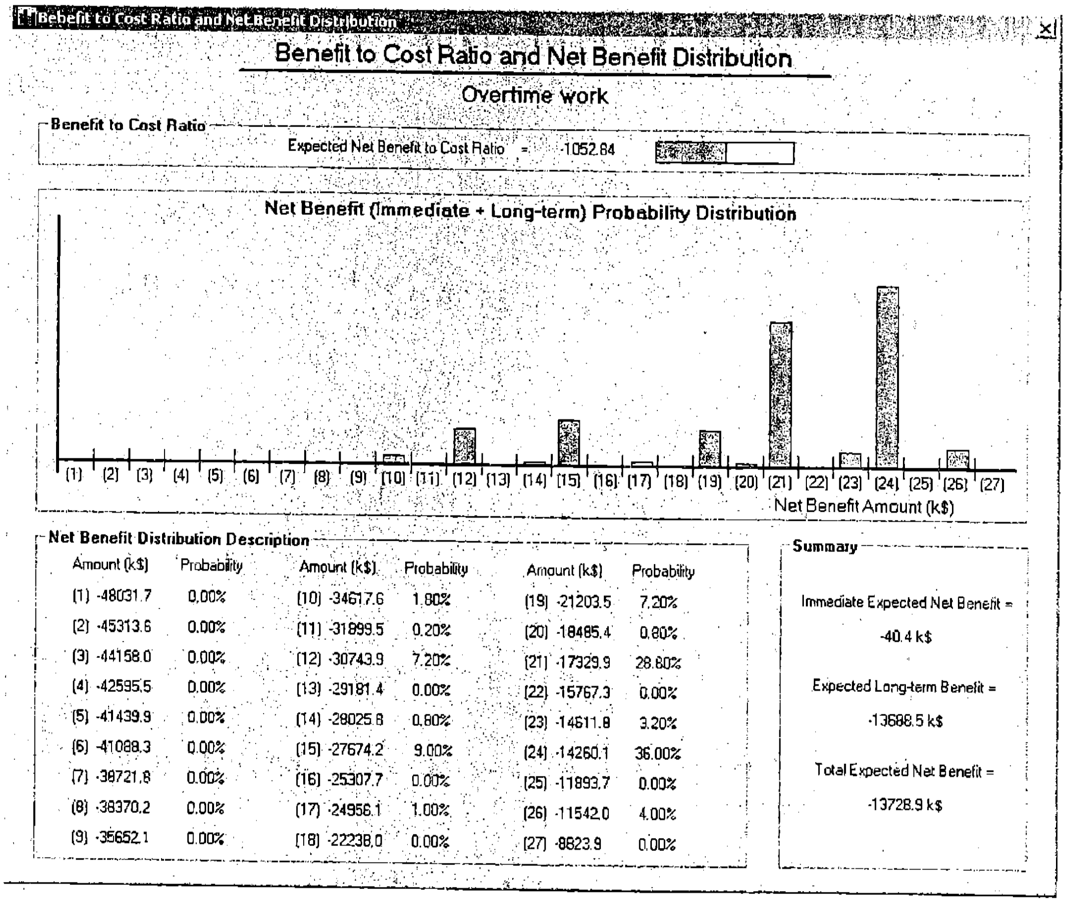
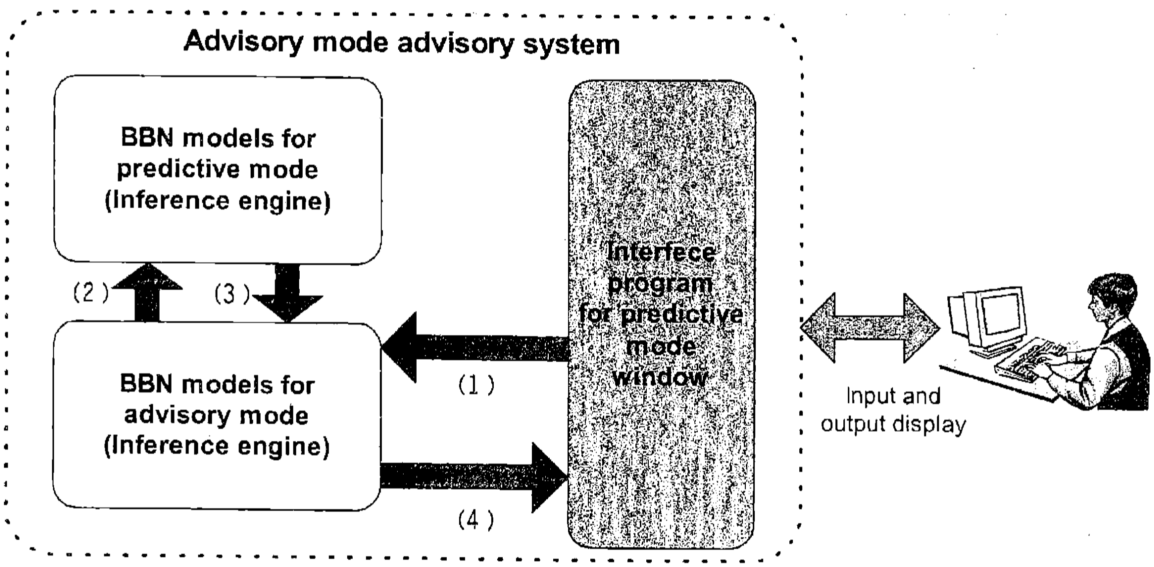


Figure 4-8. Advisory mode window for detailed information of individual action

Figure 4-9 summarizes the information flow in the advisory mode interface program. Unlike the predictive mode case, the advisory mode interface program uses both the advisory mode BBN models for identifying the optimal action and the predictive mode BBN models for predicting the project performances at the scheduled project completion time. Also, it has to handle a much larger amount of information, for example immediate cost and benefit data, long-term benefit data, than the predictive mode case.



(1) - Current evidence
- Immediate Cost & benefit data
- Long-term benefit data
- Priority functions data
- Work phase control

(3) - Project performance probability distributions at scheduled project completion time

(2) - Current evidence
- Post-action project performance probability distributions
- Work phase control

(4) - Optimal action among alternatives
- Post-action project performance probability distributions
- Project performance probability distributions at scheduled project completion time

Figure 4-9. Information flow of the advisory mode advisory system

CHAPTER 5.
SIMULATION RESULTS AND ANALYSIS

5.1 Case studies with the predictive mode BBN

Case description

Project: Nuclear Power Plant Case Study for the predictive mode BBN
Date: 156 weeks after project starts, in the work package development work phase

The evidence at 156 weeks and of the overall project performance information during the period from 156 weeks to 168 weeks is obtained from real steam generator replacement work. The current evidence of the work package development work phase and SPI and CPI histories for overall project performance is summarized in Table 5-1 and Figure 5-1, respectively. As illustrated in Table 5-1, there is no most difficult to implement group in this case study since the current evidence is for the work package development work phase. Based upon the current evidence, the future project performance predictions are computed by the predictive mode BBN and compared to the obtained real case data for benchmarking the prediction values.

Table 5-1. Evidence of project performance at 156 weeks

	Most difficult group	Medium difficult group	Least difficult group
SPI	N/A	0.995	1.000
CPI	N/A	1.056	1.015
TPI (Time)	N/A	0.987	1.000
CDI (Cost)	N/A	1.107	1.081
SCPI (Scope)	N/A	0.950	1.000
QPI (Quality)	N/A	0.950	1.000
Client satisfaction	N/A	1.050	1.000

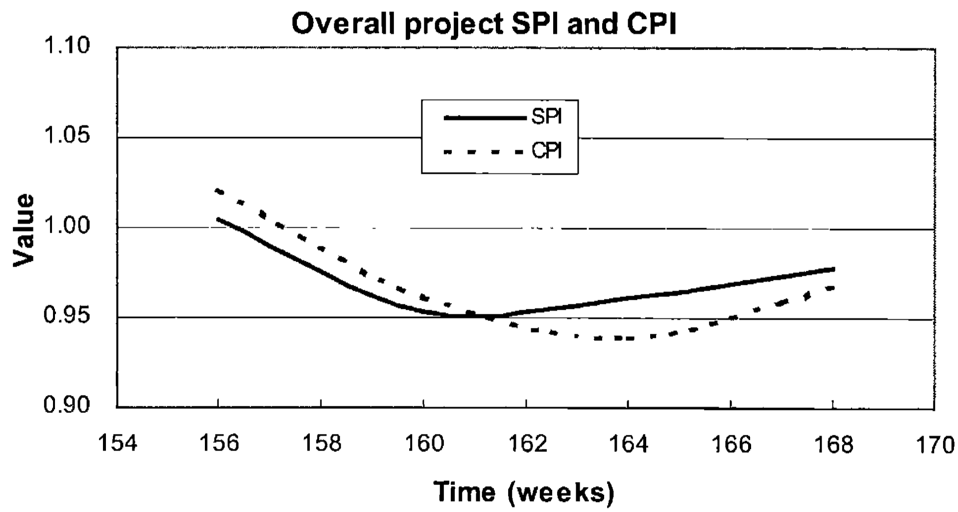


Figure 5-1. Overall project performances from 156 weeks to 168 weeks

Case analysis results

With predictive mode BBN for single work phase

Figures 5-2 and 5-3 show the predicted overall project performance (SPI and CPI, respectively) probability distributions of 1, 2 and 3 future months based upon the current evidence described in Table 5-1. In order to benchmark the predictions by the BBN models, the mean values of each probability distribution are calculated and compared to the real case values. As a result, two curves (i.e., real case data vs. prediction value) show good agreement in both SPI and CPI cases as shown in Figures 5-4 and 5-5 and the domain experts confirm this agreement. As time goes on, however, the discrepancy between two curves increases as seen in Figure 5-4 and 5-5, because the two curves represent different scenarios: 1) the real case data represents the situation of intervening management action and 2) the prediction value is from the situation of no intervening management action.

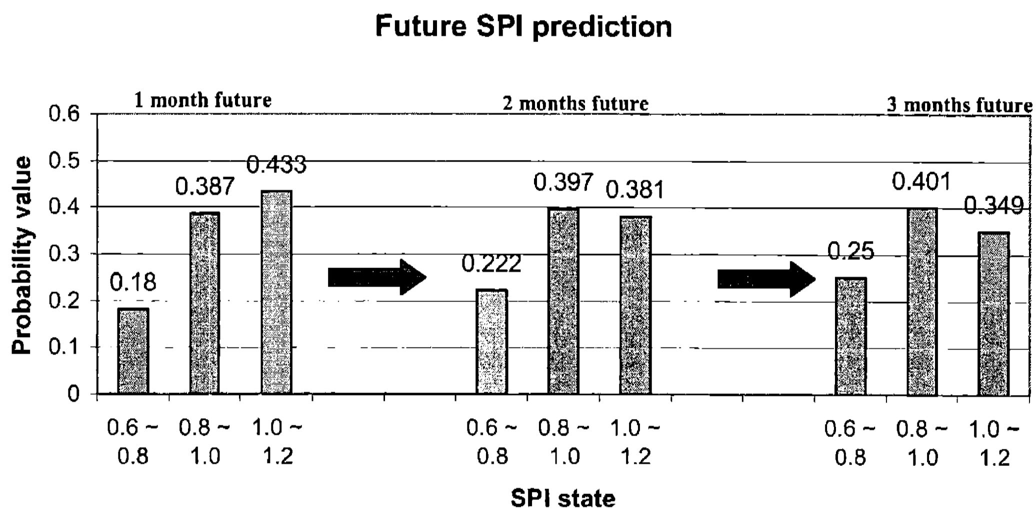


Figure 5-2. SPI prediction probability distributions for overall project of 1, 2 and 3 months future

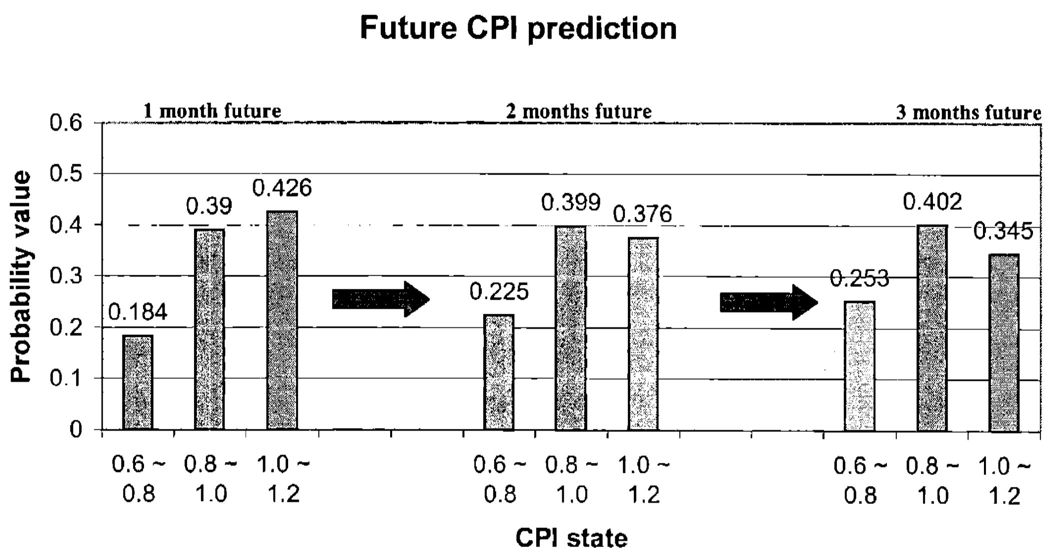


Figure 5-3. CPI prediction probability distributions for overall project of 1, 2 and 3 months future

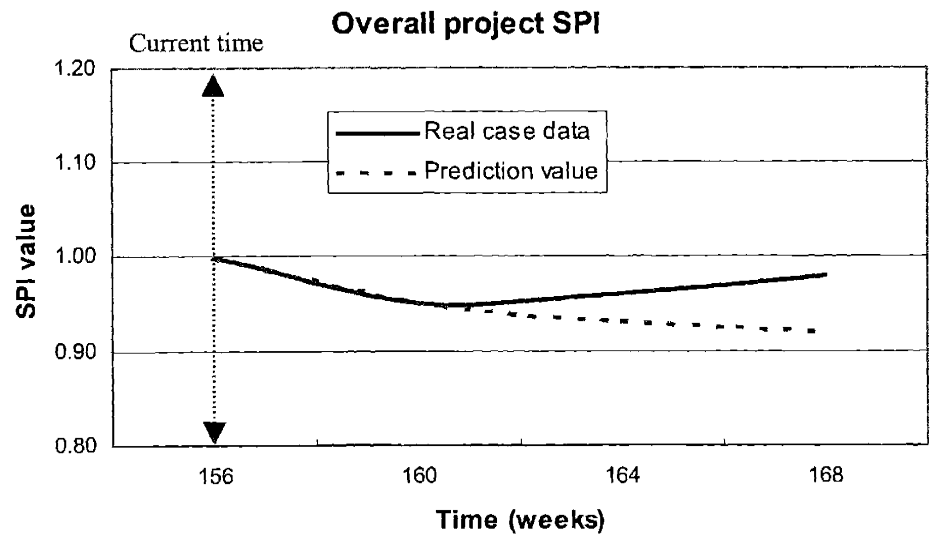


Figure 5-4. Overall project SPI real case data vs. prediction value

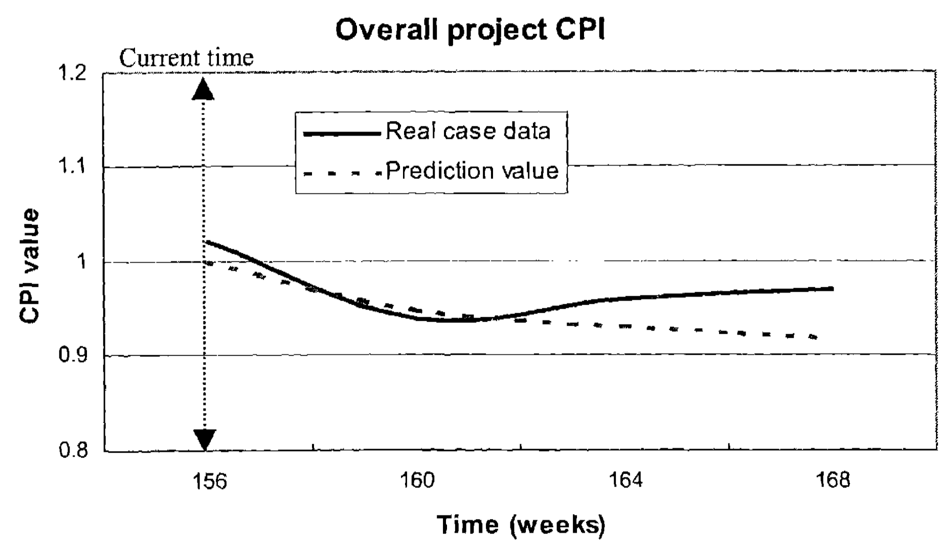


Figure 5-5. Overall project CPI real case data vs. prediction value

The prediction probability distribution will eventually go to uniform since uncertainty grows with time. At that time of uniform probability distribution, the discrepancy between two curves will show the maximum value, which indicates the maximum uncertainty. This trend of increasing uncertainty with time is illustrated in Figures 5-6 for the best scenarios case and 5-7 for the worst scenario case in the work package development work phase. Both figures show the largest possibility in the medium SPI state even in 12 months future, except the short elapse after current time, since the domain experts believe in the largest likelihood in the medium project performance from their past experiences up to now.

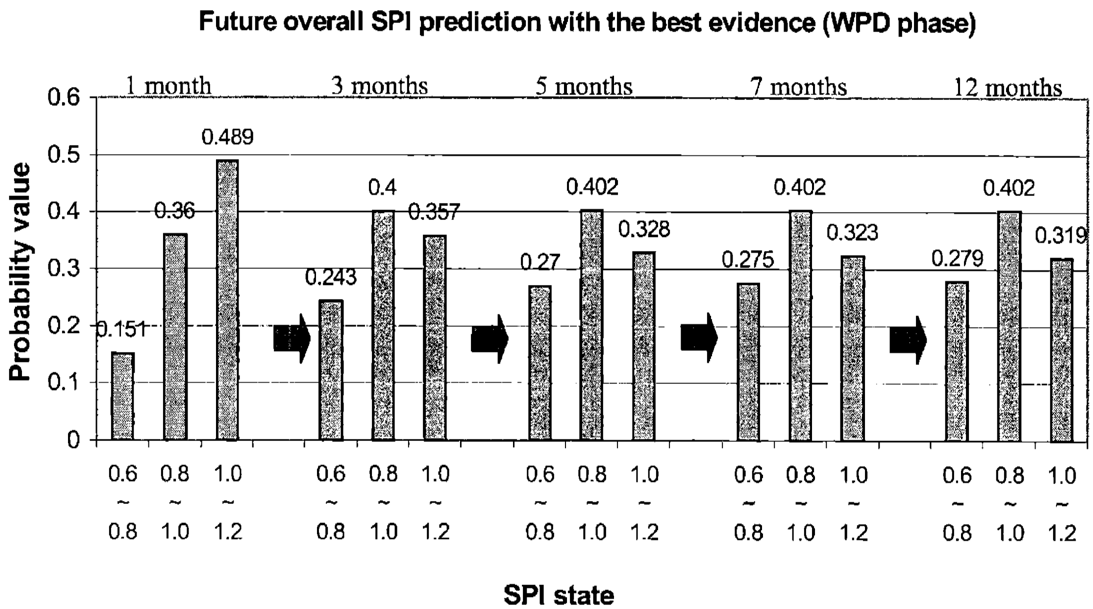


Figure 5-6. Increasing uncertainty with time for the best evidence case

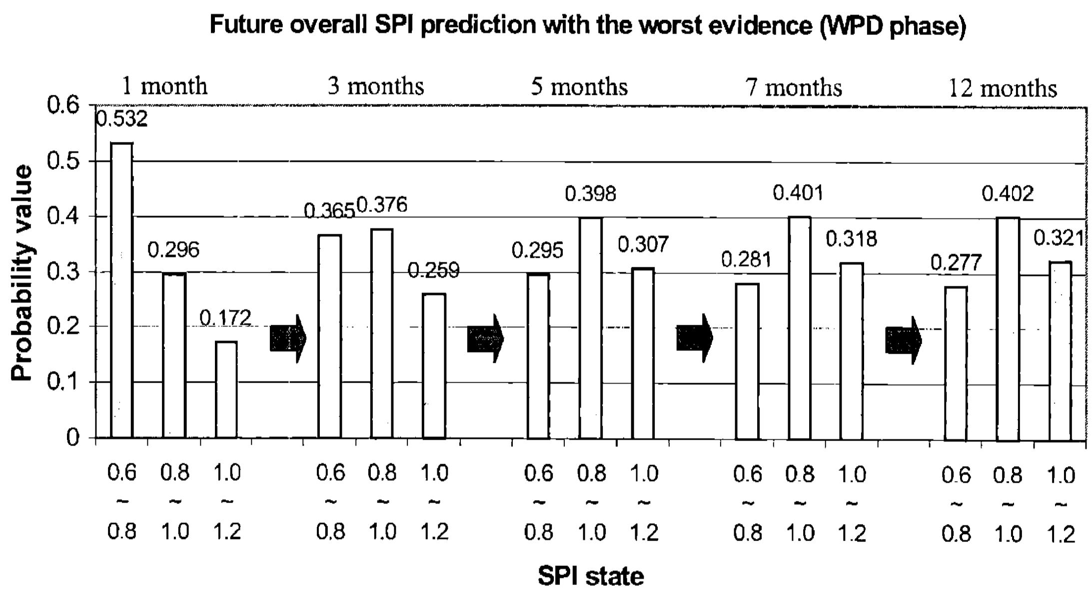


Figure 5-7. Increasing uncertainty with time for the worst evidence case

With predictive mode BBN for project lifetime

Figures 5-8, 5-9 and 5-10 show the SPI, CPI and profit probability distribution predictions at scheduled project completion time based upon the current evidence in Table 5-1. Because there was no real case information for this case, domain experts confirmed these results to be reasonable predictions.

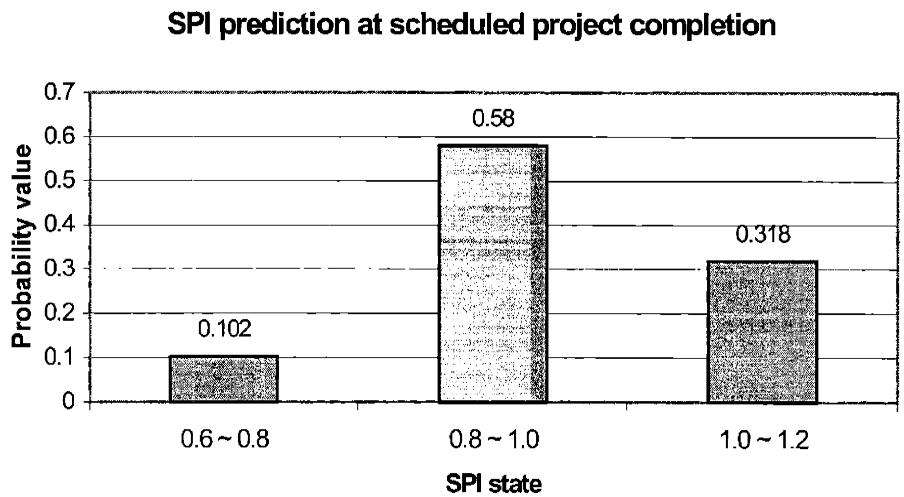


Figure 5-8. SPI performance prediction for overall project at scheduled completion time

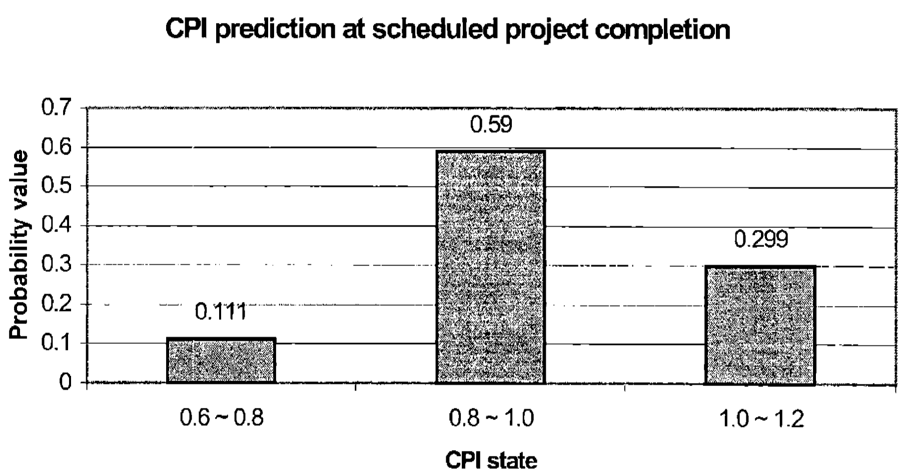


Figure 5-9. CPI performance prediction for overall project at scheduled completion time

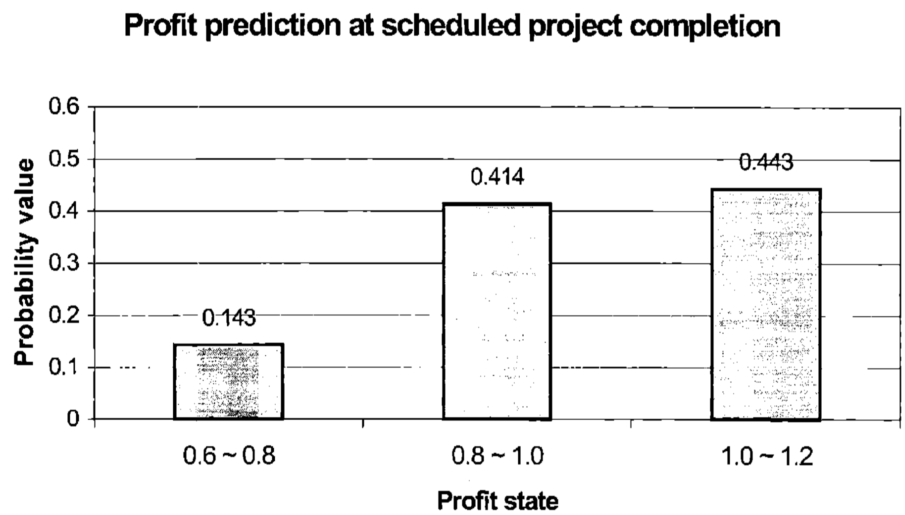


Figure 5-10. Profit performance prediction for overall project at scheduled completion time

5.2 Case study with the advisory mode BBN

Case Description

Project: Nuclear Power Plant Case Study for the advisory mode BBN

Date: 149 weeks after project starts, in the work package development work phase

As seen in Figure 5-11, the overall project shows good performance in SPI and CPI at the time of interest (149 weeks). On a total project basis, the SPI and CPI curves are very good measures to judge project health, but those measures do not tell the status of a specific part (or parts) of the overall project. This case applies to a group of work packages, which show the worst case scenario (i.e., all evidence show the worst state performances), not to overall project level in either the medium or the least difficult to implement group. Although the overall project level performance indicators appear good in Figure 5-11, the performance of a specific group of work packages may be in bad performance.

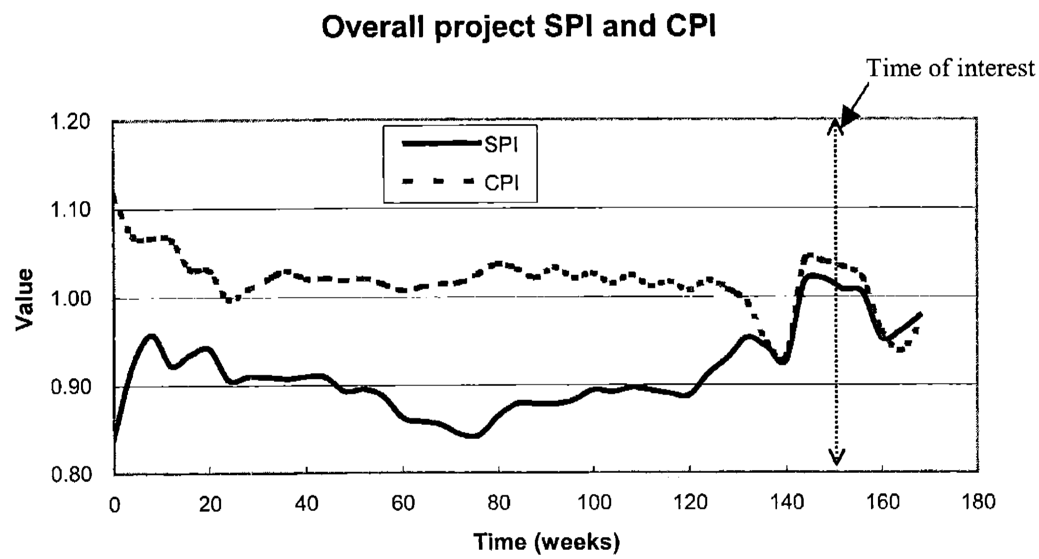


Figure 5-11. Overall project level SPI and CPI history from 0 to 173 weeks

In fact, the deadline of a specific milestone of those work packages was 161 weeks but their performance did not seem to achieve it. The project managers decided to consider the following management options to achieve this milestone. The present time is 149 weeks.

Management Options:

1. Hire Additional Resources – Hire more work forces to achieve the milestone but incur direct and non-direct costs.
2. Overtime Work (OT) – Overtime work with current work forces to obtain the milestone but incur direct and non-direct costs.
3. No action - Most likely misses the milestone and incur penalty.

Option 1 - requires two additional workers for a total of 18 man-weeks (assume 80$/man-hr) as well as indirect cost totaling around 16 k$.

Option 2 - assumes the same amount of man-effort (i.e., 720 man-hours), which results in an absolute cost of 58$/man-hr as well as indirect cost totaling around 16 k$. Note, however, that this option would also result in an overload of work to the current staff and the necessary expertise is also not in place. Thus, although the possibility of overtime work period extension would be significant, it is not reflected here (i.e., not accounted in costs).

Option 3 – basically assumes no change in project performance status from pre-action time and post-action time and no costs.

In summary, Table 5-2 shows the alternative action options and corresponding immediate costs in overall project level for the current situation.

Table 5-2. Action alternatives and corresponding immediate costs

Action alternative	Costs (k$)
Hire additional resources	74
Overtime work	57
Do nothing	0

As discussed in Section 3.4.1, the immediate benefits from taken action can be estimated from the resultant BCWS (Budgeted Cost Work Schedule) curve shift and current project SPI state. From discussions with domain experts and the record of SPI and CPI curves (i.e., Earned Value Chart), it was found that a reasonable estimation of the BCWS for that group of work packages, which show bad performance, is 5% of the total scheduled budget for the work package development work phase, which is 24,764 k$. Based upon 5% of fraction estimation, BCWS of the Work Package Development work phase and the correlations for immediate benefits in Section 3.4.1, the immediate benefits for every possible SPI curve shift between pre-action and post-action time are estimated as seen in Figure 5-12. It should be noted that a medium value of each SPI state range (e.g., 0.7 from range of (0.6 ~ 0.8)) is selected in order for immediate benefit computation. One example calculation is illustrated below.

BCWS for that group of work packages = $0.05 \times 24{,}764k\$ = 1{,}238k\$$. (5-1)

Immediate benefit from Pre-action SPI state, $0.6 \sim 0.8 \rightarrow$ Post-action SPI state, $0.8 \sim 1.0 = 0.2 \times 1{,}238k\$ = 248k\$$. (5-2)

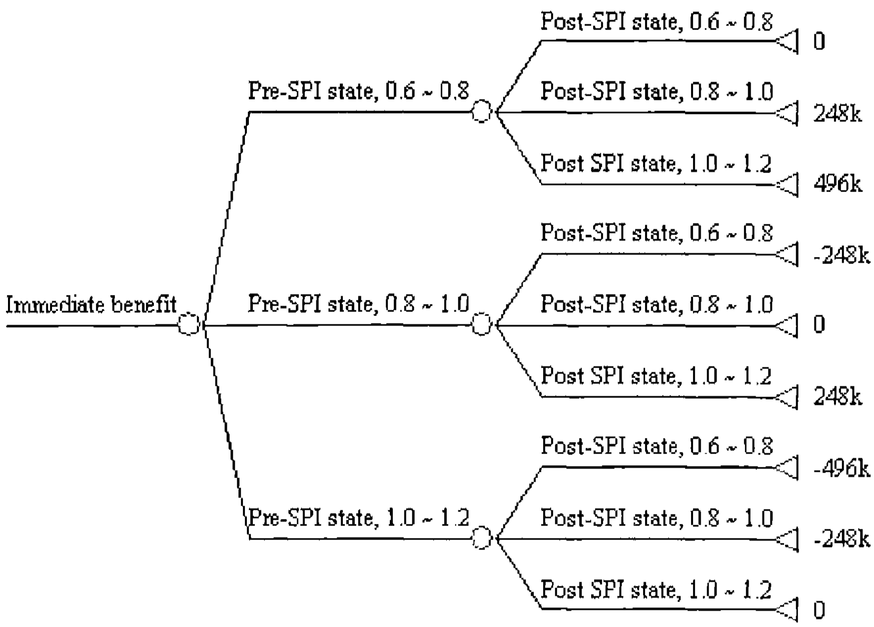


Figure 5-12. Immediate benefit tree for the advisory mode case study

Final management decision:

Management eventually chose Option 1 (Hire additional resources). Option 1 may not be an alternative with the most absolute highest expected net benefit, but the benefit of choosing that option allows the current staff to maintain pace and allows the client to gain confidence that Contractor can make their milestones.

Assumptions

It is assumed that the group of work packages that show bad performance in this case study lie in the single-work group, either in the medium or in the least difficult to implement group. Therefore, the case study is performed with both scenarios, that group of work packages in the medium difficult group and in the least difficult group. The immediate benefits as seen in Figure 5-12 are allocated to either the medium or the least difficult group according to case scenario. Also, it is assumed that the costs in the medium pre-action SPI state (0.8 ~ 1.0) have 50% of those in the worst state (0.6 ~ 0.8) and no cost in the best state (1.0 ~ 1.2), respectively. The costs are allocated in the same way as in the benefits and the immediate cost tree is illustrated in Figures 5-13.

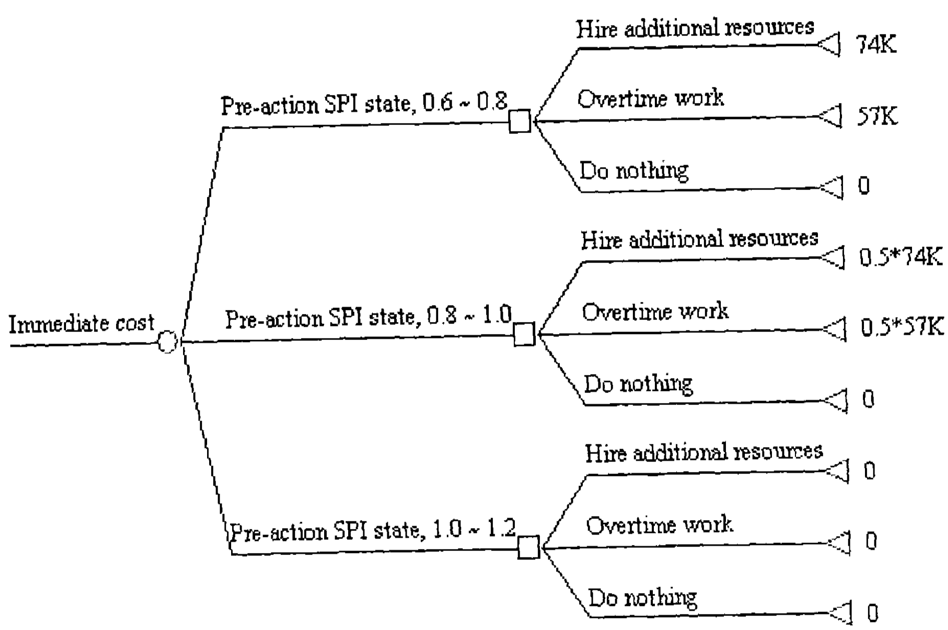


Figure 5-13. Immediate cost tree for the advisory mode case study

Case analysis results

In this situation, the project managers can have the following three questions to identify the optimal selection from alternatives. An analysis would be performed in order to answer these three questions.

1. *What is the optimal action under this situation?*
2. *What will be the post-action project performance likelihood, if the project managers take one of action from alternatives?*
3. *What will be the project performance likelihood at the scheduled project completion time, if the project managers take one of action from alternatives?*

Answer to question 1.

1. **Under the expected net benefit criterion** – The action with the largest expected net benefit is the optimal action alternative. Since there is no information on long-term penalty (penalty that comes from the costs of the domino effect originating from overdue provision of deliverables, lost reputation and so on), a sensitivity analysis has been performed on long-term benefit (or penalty). Without long-term penalty (e.g., long-term penalty value is 0 in Figures 5-14 and 5-15), the 'Do nothing' action is optimal in both scenarios (the medium and the least difficult to implement group), since it gives the largest expected net benefit as seen in Figures 5-14 and 5-15. However, as the long-term penalty grows the optimal action changes into 'Overtime work' and then 'Hire additional resources' in the medium difficult group and into 'Hire additional resources' in the least difficult group, respectively. From this result, it is recognized that the long-term penalty (or benefit) of action is the key factor in determining the optimal action under this situation. Therefore the effort is focused on estimating the long-term penalty (or benefit). This will be discussed in a later section.

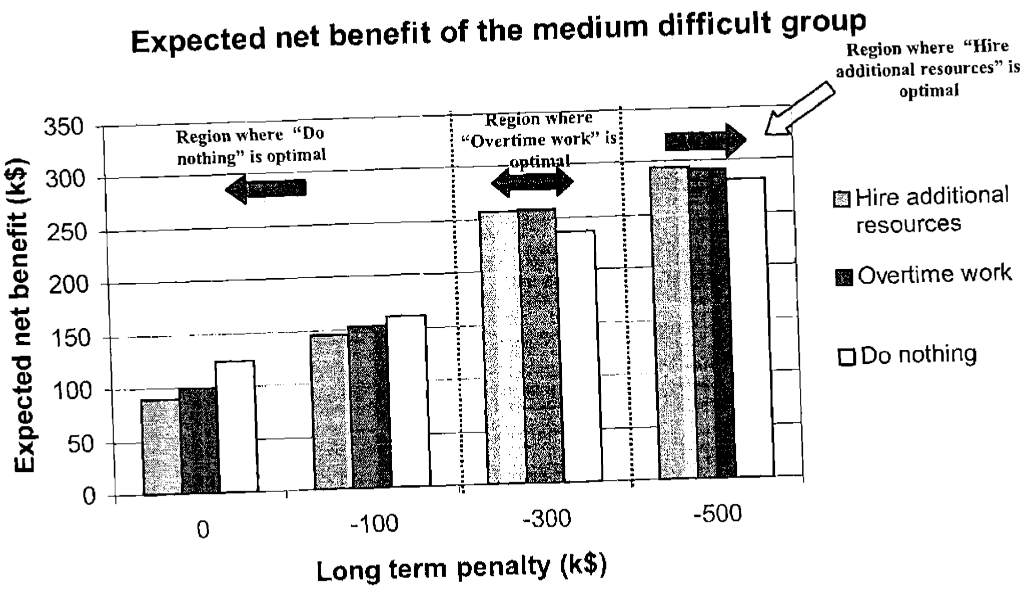


Figure 5-14. Optimal action under expected net benefit criterion in the medium difficult group scenario

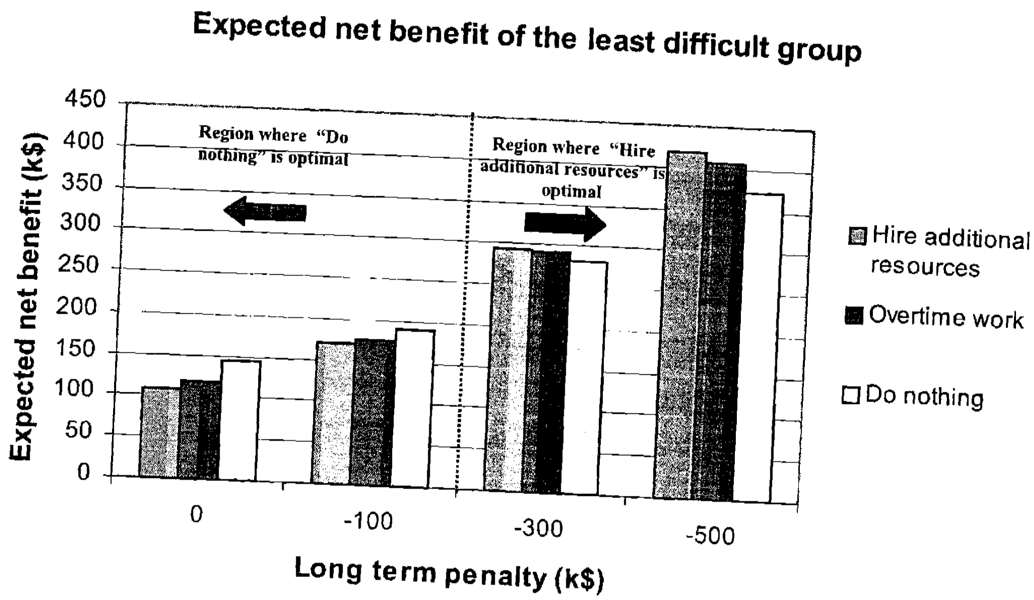


Figure 5-15. Optimal action under expected net benefit criterion in the least difficult group scenario

Answer to question 2.

One of main concerns of the project managers regarding a bad project performance condition is what will be the project performance after taking one of the actions from the list of alternatives. As discussed in an earlier section, the advisory mode BBN can determine the post-action project performance likelihood corresponding to the taken action. The term 'post-action' is the short time period elapsed that can show the effect of action, generally from 1 to 3 months. In this case study, three action alternatives are considered: 1) Hire additional resources, 2) Overtime work and 3) Do nothing. Figures 5-16, 5-17 and 5-18 show the post-action project performance probability distributions for each action alternative. From the resultant post-action project performance, the action 'Hire additional resources' gives the best project performance likelihood, making it the optimal choice.

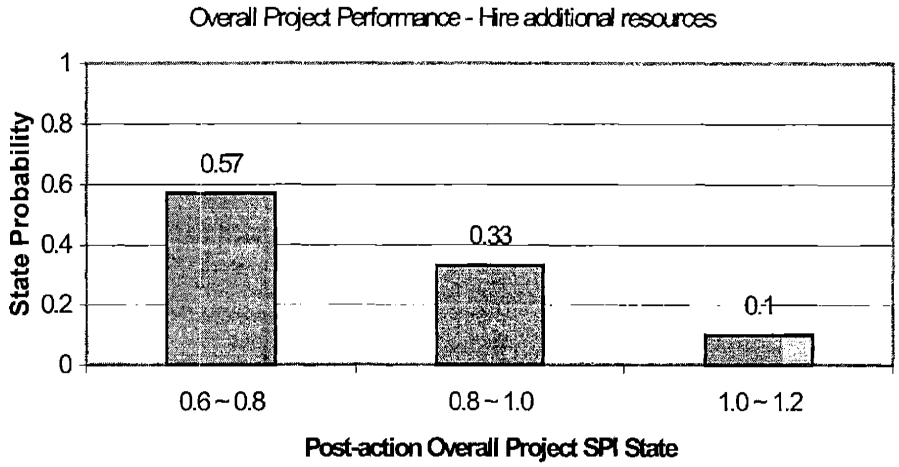


Figure 5-16. Post-action project performance after taking 'Hire additional resources'

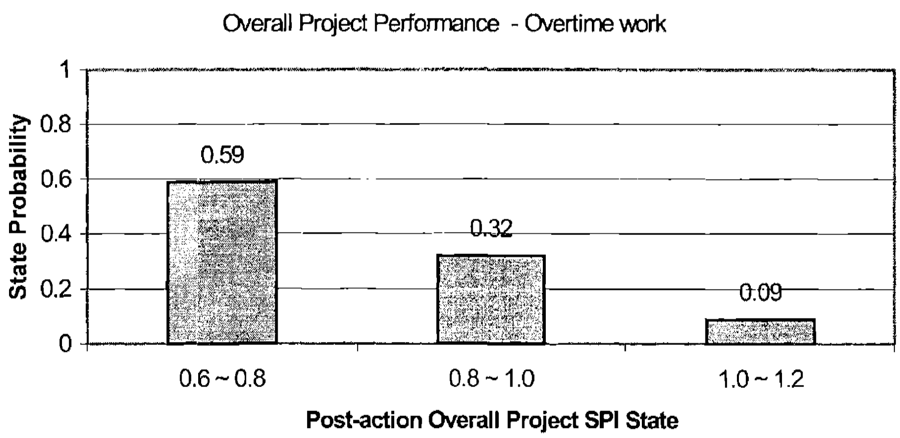


Figure 5-17. Post-action project performance after taking 'Overtime work'

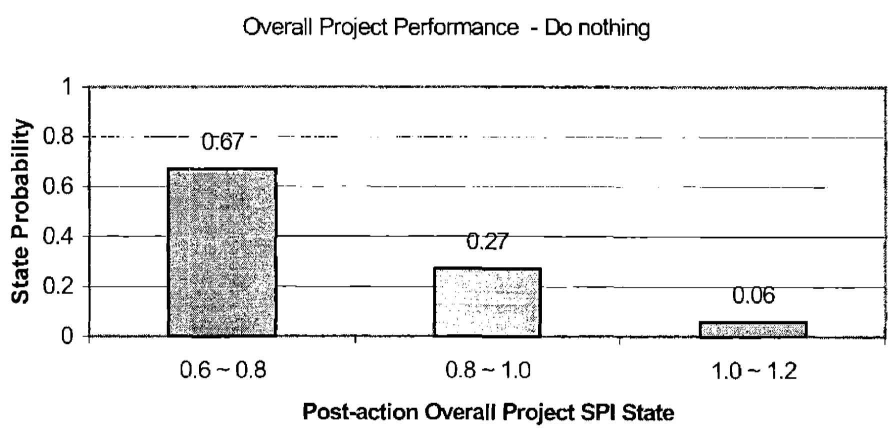


Figure 5-18. Post-action project performance after taking 'Do nothing'

Answer to question 3.

Project managers are concerned most about the project performance at the scheduled project completion time since they have to pay a large penalty if they fail to meet the schedule. Especially in the steam generator replacement project of nuclear power plants, the time schedule is a very critical factor because the penalty amount is up to several million dollars per even one-day delay. In addition, they may lose the company's reputation and hence, future business opportunities in the market. Therefore, whether or not they can meet the schedule at the project completion time is one of the most important factors in the decision-making process.

Project performance predictions at scheduled project completion time for each action alternative are shown in Figures 5-19, 5-20 and 5-21. As expected, the action 'Hire additional resources' gives the best project performance prediction since the post-action project performance was found to be the best from answer to question 2. Therefore, the action 'Hire additional resources' is the optimal one based upon the project performance at the scheduled project completion time.

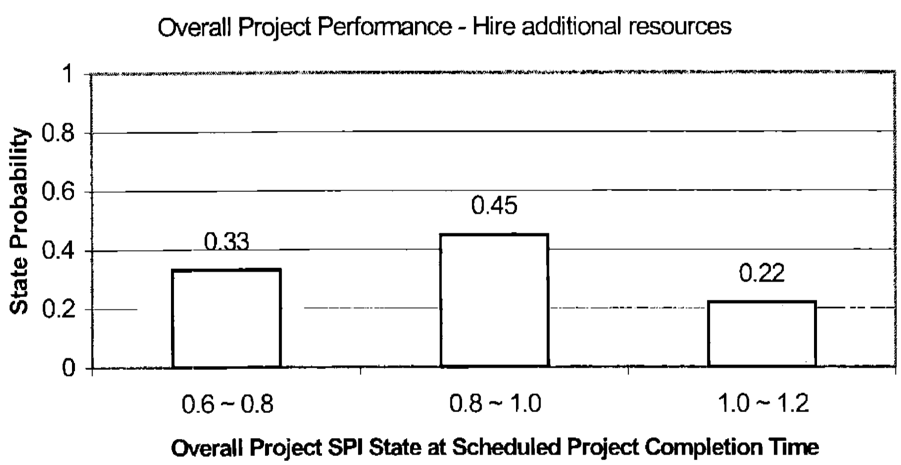


Figure 5-19. Project performance at scheduled project completion time after taking 'Hire additional resources'

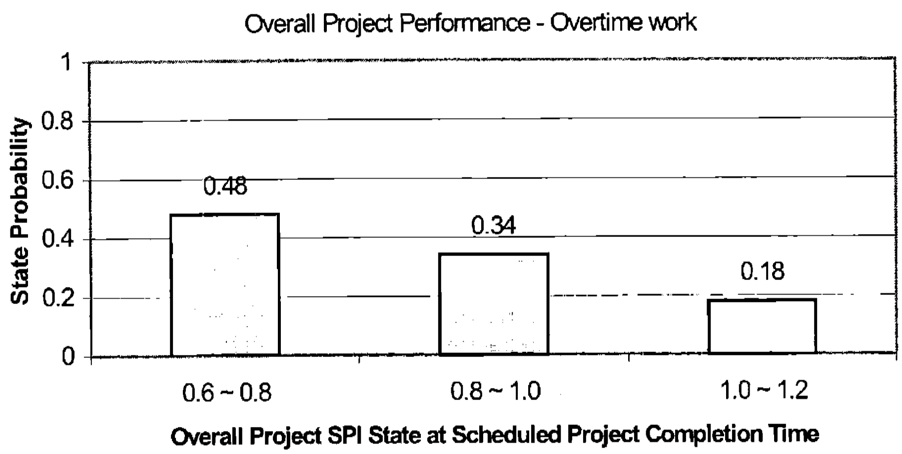


Figure 5-20. Project performance at scheduled project completion time after taking 'Overtime work'

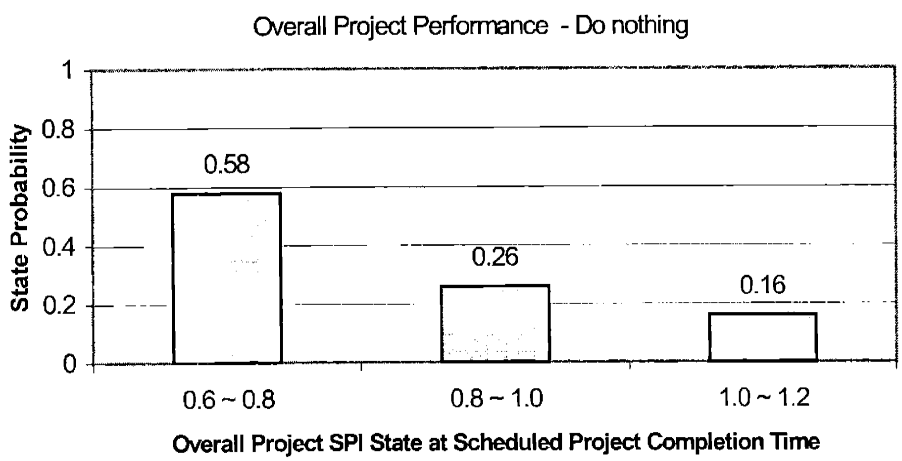


Figure 5-21. Project performance at scheduled project completion time after taking 'Do nothing'

Survey for probability distributions for long-term benefit (or penalty)

As discussed in Section 3.4.1 and illustrated in Figures 5-14 and 5-15, there are two types of benefits for project management, immediate benefits (or penalty) and long-term benefits (or penalty), and the long-term benefit is a more important key factor in the management decision-making process than the immediate benefit because the long-term benefit is much larger than the immediate benefit. Therefore, the long-term benefits are estimated under the assumption of a known project performance state at the scheduled completion time and corresponding preference functions of project mangers based upon evaluated long-term benefit values through survey with project managers in real world. The term 'scheduled project completion time' means the time that the project is supposed to be completed in the current project schedule. However, the long-term benefit values have very large uncertainties. As discussed, the best way to include such large uncertainties into the analysis is to estimate the long-term benefit values as probability distributions. Three discrete probability distributions (i.e., one pmf[4] for X1, one pmf for X2 and one pmf for X3 - see Table 3-8 for X1, X2 and X3) with three values in each distribution (i.e., 3 long-term benefit values and corresponding probability values for X1, X2 and X3 in each probability distribution) were estimated, as illustrated in Figure 5-22. The reason to select three values in each distribution can be found in Section 3.6.4. Table 5-3 shows an example long-term benefit probability distribution for X1.

Table 5-3. Example long-term benefit probability distribution (pmf) for X1

Long-term benefit (k$)	X11	X12	X13
Corresponding probability value	P1	P2	P3

Note: P1+P2+P3=1.0

[4] Probability mass function (pmf) is another name of discrete probability distribution.

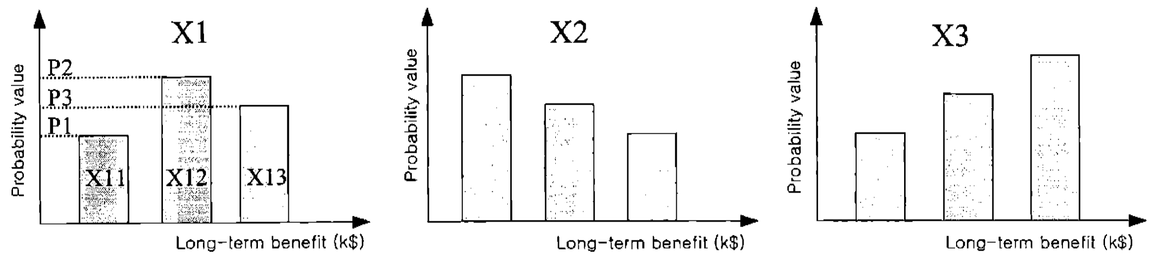


Figure 5-22. Example discrete probability distributions for long-term benefits

Questionnaire for estimating the long-term benefit distributions

The next step is to ask several questions in order to estimate your long-term benefit. **It should be noted that long-term benefit probability distributions are most likely to be different from one situation to another. Therefore, long-term benefit probability distributions should be reevaluated whenever the situation changes.**

Question 1.

Which components in the following equations are proper to your situation?

Case 1. SPI at scheduled project completion time is under 1.0

Total long-term penalty value = Tangible penalty + Intangible penalty

Tangible penalty = Additional labor cost + Additional material cost + Penalty in contract

Intangible penalty = Company's reputation loss

Case 2. SPI at scheduled project completion time is 1.0 or over 1.0

Total long-term benefit value = Tangible benefit + Intangible benefit

Tangible benefit = Gains from under-spent project budget + Incentive from project owner company

Intangible benefit = Improved company's reputation

Question 2.

What is the range of each component of long-term benefit value, which is identified in *Question 1*? The range should be evaluated for three different cases: 1) scheduled project completion time SPI of 0.6 ~ 0.8, 2) SPI of 0.8 ~ 1.0 and 3) SPI of 1.0 ~ 1.2.

Question 3.

What is the range of the long-term benefit value (i.e., the sum of every components evaluated in *Question 2*)? The ranges should be evaluated for three different cases: 1) scheduled project completion time SPI of 0.6 ~ 0.8, 2) SPI of 0.8 ~ 1.0 and 3) SPI of 1.0 ~ 1.2.

Question 4.

From the three different SPI ranges (i.e., 0.6 ~ 0.8, 0.8 ~ 1.0 and 1.0 ~ 1.2), what is the most likely value from each range of long-term benefit value, which were evaluated in *Question 3*? Then enter those values in Tables 5-4, 5-5 and 5-6 according to proper SPI ranges.

Question 5.

Please pick up one representing value from upper part and another representing value from lower part of each range of long-term benefit value as seen in Figure 5-23, which were evaluated in *Question 3*. We have six representing values from three different SPI ranges (i.e., 0.6 ~ 0.8, 0.8 ~ 1.0 and 1.0 ~ 1.2). Then enter those values in Tables 5-4, 5-5 and 5-6 according to proper SPI ranges.

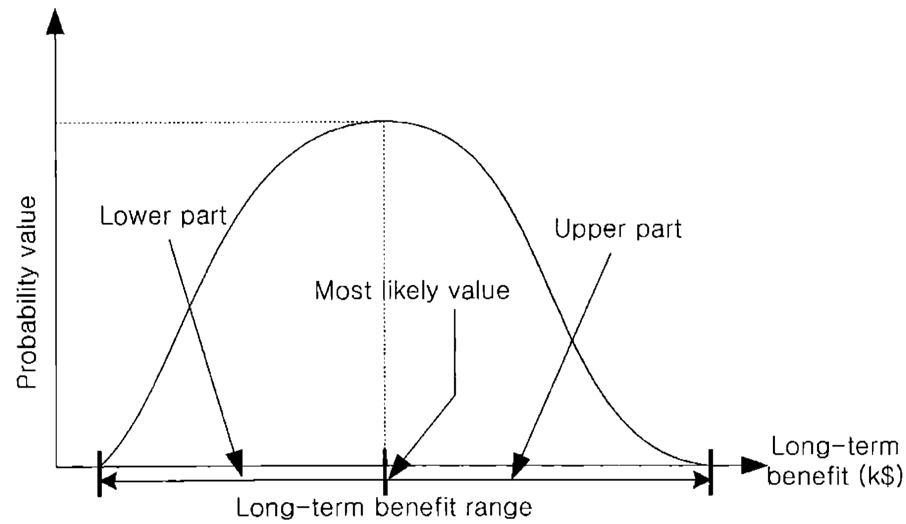


Figure 5-23. Example long-term benefit value range

Question 6.

Please evaluate the proper probability value to each long-term benefit value in Tables 5-4, 5-5 and 5-6 and enter that probability value into the corresponding Tables. You may use the probability value scale in Figure 5-24 below. In case of certainty of single value, then enter that single long-term benefit value and corresponding probability value as 1.0 into the tables. The other two spaces for probability values in those tables should be all 0s.

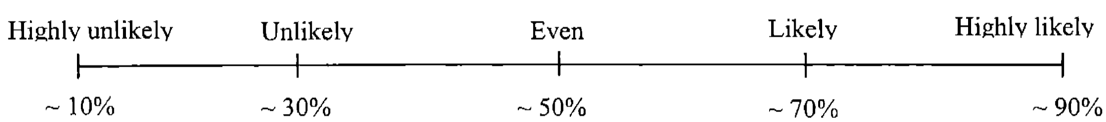


Figure 5-24. Probability value scale

Table 5-4. Long-term benefit probability distribution (pmf) for SPI – 0.6 ~ 0.8

Long-term benefit (k$)			
Corresponding probability value			

Note) Sum of three probability values should be 1.0

Table 5-5. Long-term benefit probability distribution (pmf) for SPI – 0.8 ~ 1.0

Long-term benefit (k$)			
Corresponding probability value			

Note) Sum of three probability values should be 1.0

Table 5-6. Long-term benefit probability distribution (pmf) for SPI – 1.0 ~ 1.2

Long-term benefit (k$)			
Corresponding probability value			

Note) Sum of three probability values should be 1.0

Survey results for probability distributions for long-term benefit (or penalty)

Two companies are currently performing steam generator replacement work in the market: 1) Bechtel and 2) Framatome ANP Duke Engineering and Service (DE&S). Since the first steam generator replacement at a U.S. nuclear power plant more than 20 years ago, Bechtel has performed more steam generator replacement work than any other contractor in this market. The other company, Framatome ANP DE&S began performing steam generator replacement work in 1996 at Catawba Nuclear Station Unit 1 and McGuire Nuclear Station Units 1 and 2. As date of October 2000, Bechtel has performed 24 steam generator replacement projects as the prime contractor, compared to its next closest competitor with four projects. In addition, Bechtel has earned several high achievements such as: 1) shortest overall replacement schedule, 2) lowest U.S. steam generator replacement accumulated radiation exposure, 3) first U.S. one-piece replacement and others. Therefore Bechtel is a leading company in the U.S. steam generator replacement market. Tables 5-7 and 5-8 show the nuclear power plants for which steam generators were replaced by Framatome ANP DE&S and Bechtel, respectively.

Table 5-7. U.S. Nuclear power plant of which SG replaced by Framatome ANP DE&S

Unit	Owner(s)	Operator	First commercial operation date
Calvert Cliffs 1	Constellation Energy Group	Constellation Nuclear	05/1975
Calvert Cliffs 2	Constellation Energy Group	Constellation Nuclear	04/1977
Catawba 1	NC Eastern Municipal Power Agency (56.25%) Duke Energy Corp. (25%) Saluda River Electric Coop (18.75%)	Duke Energy Nuclear LLC	06/1985
Indian Point 2	Energy Nuclear Operations	Entergy Nuclear	08/1974
McGuire 1	Duke Energy Corp.	Duke Power	12/1981
McGuire 2	Duke Energy Corp.	Duke Power	03/1984
St. Lucie 1	FPL Group	Florida Power and Light	12/1976

Table 5-8. U.S. Nuclear power plant of which SG replaced by Bechtel as of Oct. 2000

Unit	Owner(s)	Operator	First commercial operation date
Arkansas Nuclear One 2	Entergy Arkansas, Inc.	Entergy Nuclear	03/1980
Braidwood 1	Exelon	Exelon	07/1988
Byron 1	Exelon	Exelon	09/1985
Cook 1	American Electric Power	Indiana Michigan Power	08/1975
Farley 1	Alabama Power	Southern Nuclear Operating Co.	12/1977
Farley 2	Alabama Power	Southern Nuclear Operating Co.	07/1981
Ginna	RGS Energy Group	Rochester Gas & Electric Corp.	07/1970
Indian Point 3	Energy Nuclear Operations	Entergy Nuclear	08/1976
Kewaunee	Wisconsin Public Service Alliant Energy	Nuclear Management Co.	06/1974
North Anna 1	Dominion Virginia Power Old Dominion Electric Coop.	Dominion Generation	06/1978
North Anna 2	Dominion Virginia Power Old Dominion Electric Coop.	Dominion Generation	12/1980
Palisades	CMS Energy Corp.	Nuclear Management Co.	12/1971

Palo Verde 2	Arizona Public Service Other 6 companies	Arizona Nuclear Power Project	09/1986
Robinson	Progress Energy	Carolina Power & Light Co.	03/1971
Sequoyah 1	Tennessee Valley Authority	Tennessee Valley Authority	07/1981
Shearon Harris	Progress Energy NC Eastern Municipal Power Agency	Carolina Power & Light Co.	05/1987
South Texas Project 1	Reliant Energy HL&P Other 3 companies	STP Nuclear Operating Co.	08/1988
South Texas Project 2	Reliant Energy HL&P Other 3 companies	STP Nuclear Operating Co.	06/1989
Summer	South Carolina Electric & Gas South Carolina Public Service Authority	South Carolina Electric & Gas Co.	01/1984
Turkey Point 3	FPL Group	Florida Power & Light	12/1972
Turkey Point 4	FPL Group	Florida Power & Light	09/1973

After reviewing the U.S. nuclear power plants whose steam generator has already been replaced in Tables 5-7 and 5-8, the first commercial operating date and NEI's (Nuclear Energy Institute) license renewal report (http://www.nei.org), the number of U.S. unclear units considered as candidate future customers to Bechtel and Framatome ANP DE&S is estimated as 22. Based upon this number and other factors below, the reference reputation value is estimated from the standpoint of future business opportunities as in equation (5-3).

1. Contract price = 150M$/contract
2. Number of reactors that will replace the S/G in future = 22
3. Profit margin = 10% (after taxes)
4. Market share of Framatome ANP DE&S = 50%

$$\text{Reputation value (Future profit)} = 150\text{M\$} \times 22 \times 0.1 \times 0.5 = 165\text{M\$}\,. \qquad (5\text{-}3)$$

Based upon the reference reputation value in equation (5-3), the long-term intangible benefit (or penalty) and the long-term tangible benefit (or penalty) as a function of the SPI state at scheduled project completion time are estimated as shown in Figures 5-25 and 5-26. The reputation of a company is believed to be very fragile. It can be easily lost and, once lost, takes a much longer time and a larger effort to restore. This fact can be confirmed in this survey result again as shown in Figure 5-25. In the case of failure to meet the scheduled project completion time (i.e., under SPI value of 1.0), the intangible loss increases very rapidly. However, in the case of being ahead of schedule (i.e., over SPI value of 1.0), the intangible benefit increases slowly.

With the help of estimated long-term intangible and tangible benefits (or penalty) and equations (3-5) & (3-6), the long-term benefit (or penalty) probability distributions as a function of the SPI state at scheduled project completion time are evaluated as illustrated in Figures 5-27, 5-28 and 5-29.

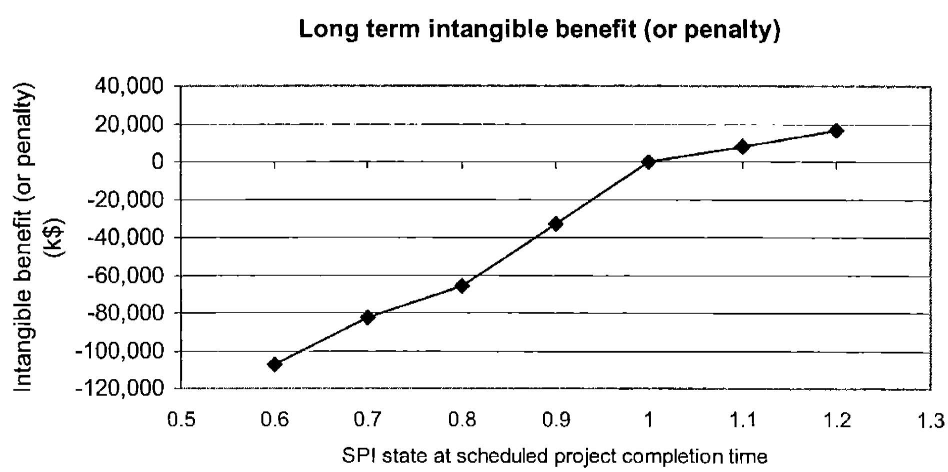


Figure 5-25. Long-term intangible benefit as function of SPI state at scheduled project completion time

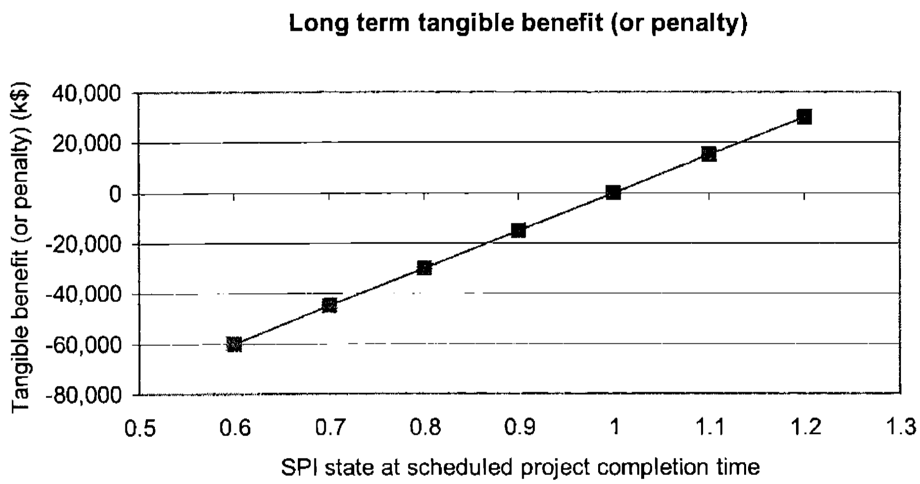


Figure 5-26. Long-term tangible benefit as function of SPI state at scheduled project completion time

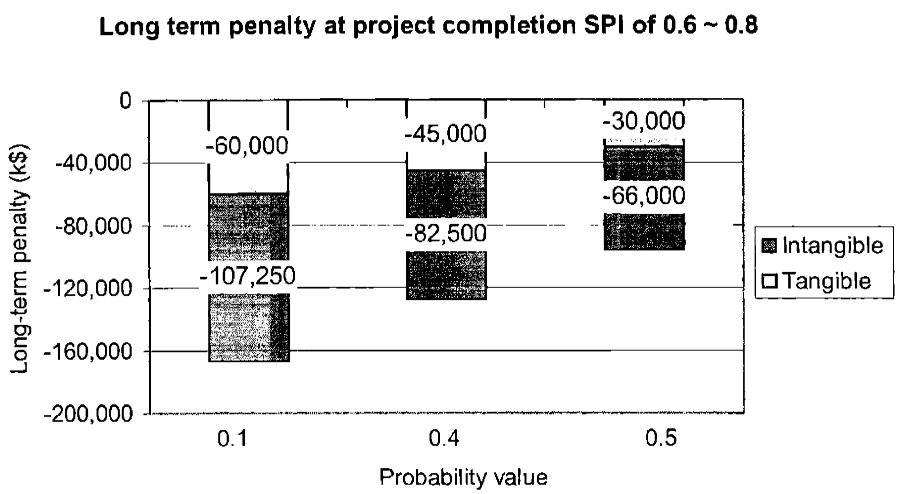


Figure 5-27. Long-term penalty probability distribution for SPI of 0.6 ~ 0.8 at scheduled project completion time

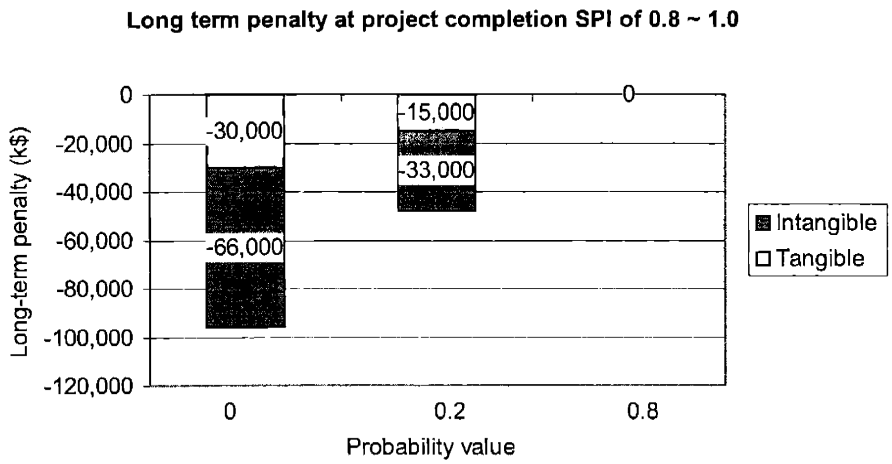


Figure 5-28. Long-term penalty probability distribution for SPI of 0.8 ~ 1.0 at scheduled project completion time

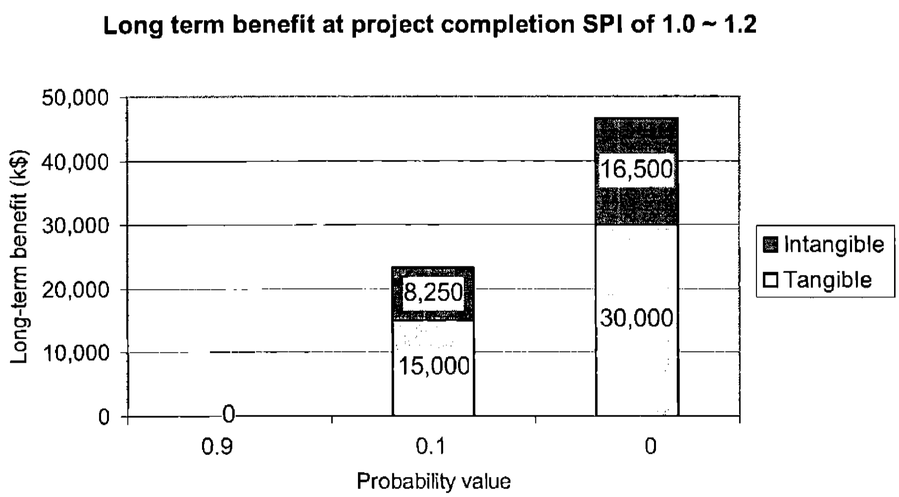


Figure 5-29. Long-term penalty probability distribution for SPI of 1.0 ~ 1.2 at scheduled project completion time

Survey for evaluating preference functions

Decisions based upon expected monetary values (i.e., expected net benefits) would be convenient, but it can lead to decisions that may not be right. Using expected net benefits to make decisions means that the decision maker is considering only the average or expected payoff. If a long-run frequency approach is used, the expected value is the average amount over many trials. However, the expected net benefit approach does not capture one important point, decision maker's attitude to risk in uncertain situations. In order to overcome this limitation, another decision criterion, the expected utility, based upon the decision theory concerned with measurement and representation of the decision maker's preferences is proposed. Utility theorists focus on accounts of preferences in rational decision making, where an individual's preferences cohere with associated beliefs and actions. *Utility* refers to the scale on which preference is measured.

There are difficulties in evaluating the utility function in this case because both the large amount of penalties (i.e., negative monetary values) and benefit values (i.e., positive monetary values) should be considered at the same time. Therefore, the preference to risk scale for measuring the decision maker's attitude to risk is developed. With this preference scale, individuals who are afraid of risk or are sensitive to risk show the small values of preference in penalties and the large values of preference in benefits as shown in Figure 5-30. The other two attitudes to risk are risk-neutral (i.e., no dependency on risk) and risk-seeking. For the person who is risk-neutral, maximizing expected net benefit gives the same result as maximizing expected utility.

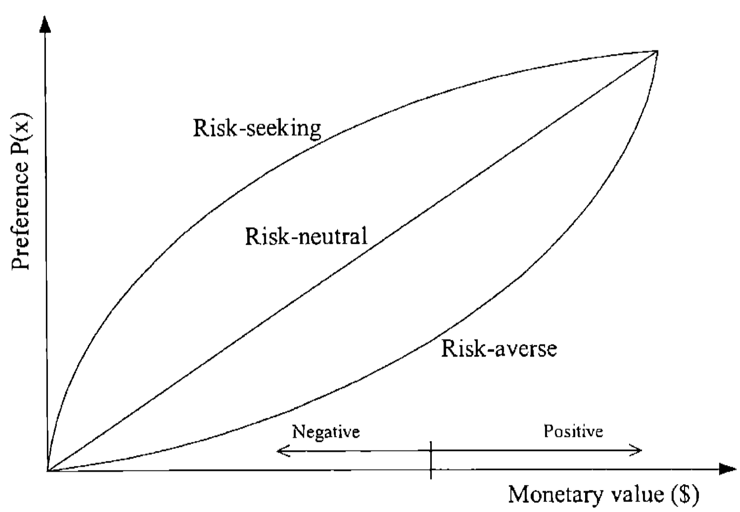


Figure 5-30. Three different preference functions

Now, in order to evaluate preference functions, several questions are asked. Note that these may be either two of points of view in the risk preference: 1) company point of view and 2) personal (i.e., project manager) point of view. In this case, estimate the risk preference based upon the company point of view. Then, answer the questions and evaluate the risk preference to expected net benefit values in monetary scale.

Questionnaire for estimating the preference functions

Question 1.

Please find the maximum and minimum values among the assigned nine long-term benefit values from Table 5-4, 5-5 and 5-6 above. Assume that the maximum and minimum values are X, Y, respectively and then, highly likely, X would be positive (benefit) and Y is negative (penalty).

Question 2.

Please enter those two values (X and Y) into Table 5-9 and then calculate remaining six long-term benefit values (i.e., 3X/4, X/2, X/4, Y/4, Y/2 and 3Y/4) in Table 5-9. After that, assign your preference to each long-term benefit value according to preference scale in Figure 5-31.

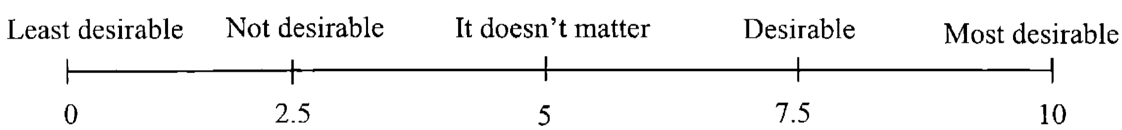


Figure 5-31. Preference scale between 0 and 10

Table 5-9. Preference function of long-term benefit values for overall project

Long-term benefit value (k$)	Your preference
Maximum = X	10
3*Maximum/4 = 3X/4	

Maximum/2 = X/2	
Maximum/4 = X/4	
0	
Minimum/4 = Y/4	
Minimum/2 = Y/2	
3*Minimum/4 = 3Y/4	
Minimum = Y	0

Question 3.

Please estimate how much fraction of project budget that would be spent on each work group: 1) most difficult work group - α, 2) medium difficult work group - β and 3) least difficult work group - γ. It should be noted the sum of α, β, γ should be 1.0. In case of early three work phases (conceptual design, detailed design and work package development work phases), the most difficult work group does not exist. Therefore, there is no need to consider the most difficult work group (i.e., Table 5-10 because α=0) and the sum of β, γ should be 1.0.

Question 4.

Please calculate the long-term benefit values (i.e., such as α*X/4) in Tables 5-10, 5-11 and 5-12. Then, enter those calculated long-term benefit values (k$) into Tables 5-10, 5-11 and 5-12.

Question 5.

Please assign your preference value for each long-term benefit value in Tables 5-10, 5-11 and 5-12 according to preference scale in Figure 5-31 above.

Table 5-10. Preference function of long-term benefit for most difficult work group

Long-term benefit value (k$)	Your preference
α*Maximum = α*X	10
α*3*Maximum/4 = α*3X/4	
α*Maximum/2 = α*X/2	
α*Maximum/4 = αX/4	
0	
α*Minimum/4 = α*Y/4	
α*Minimum/2 = α*Y/2	
α*3*Minimum/4 = α*3Y/4	
α*Minimum = α*Y	0

Table 5-11. Preference function of long-term benefit for medium difficult work group

Long-term benefit value (k$)	Your preference
β*Maximum = β*X	10
β*3*Maximum/4 = β*3X/4	
β*Maximum/2 = β*X/2	
β*Maximum/4 = β*X/4	
0	
β*Minimum/4 = β*Y/4	
β*Minimum/2 = β*Y/2	
β*3*Minimum/4 = β*3Y/4	
β*Minimum = β*Y	0

Table 5-12. Preference function of long-term benefit for least difficult work group

Long-term benefit value (k$)	Your preference
γ*Maximum = γ*X	10
γ*3*Maximum/4 = γ*3X/4	
γ*Maximum/2 = γ*X/2	
γ*Maximum/4 = γ*X/4	
0	
γ*Minimum/4 = γ*Y/4	
γ*Minimum/2 = γ*Y/2	
γ*3*Minimum/4 = γ*3Y/4	
γ*Minimum = γ*Y	0

Survey results for preference functions

Based upon the long-term benefit (or penalty) values estimated in the previous survey, the preference functions are evaluated as shown in Figures 5-32, 5-33, 5-34 and 5-35. As expected, negative monetary values show low preferences and positive monetary values show high preferences – risk aversion type decision makers.

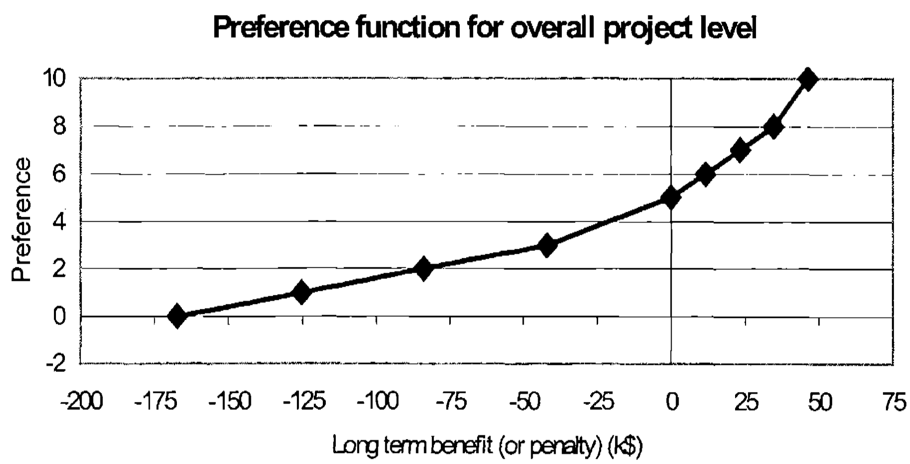


Figure 5-32. Preference function for overall project level

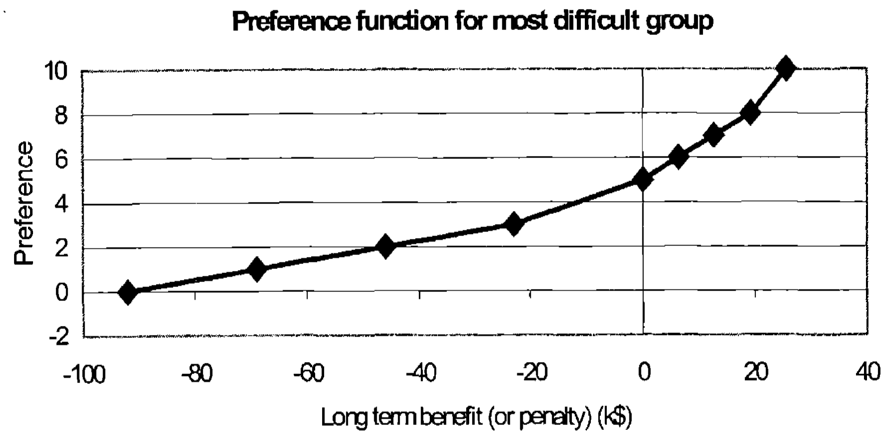


Figure 5-33. Preference function for the most difficult to implement group

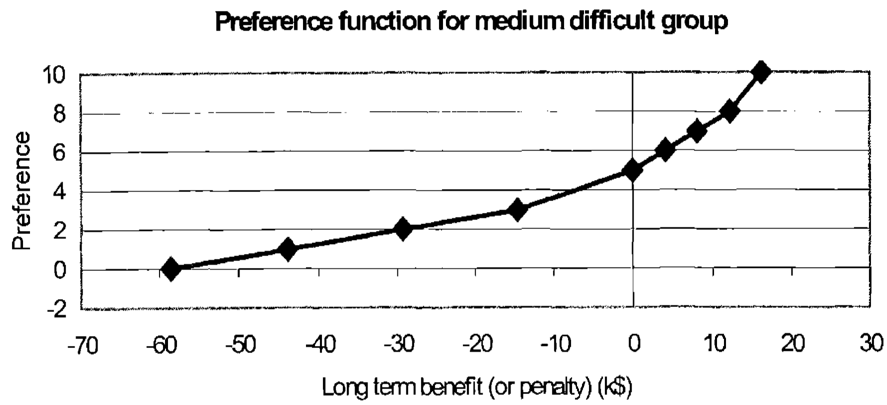


Figure 5-34. Preference function for the medium difficult to implement group

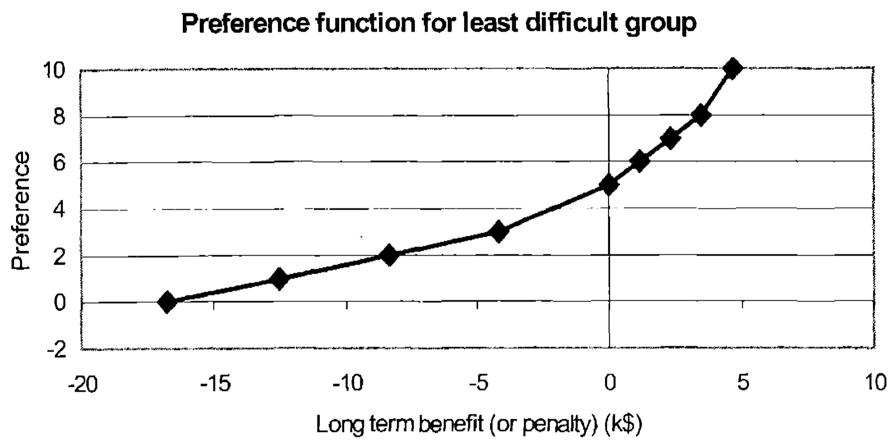


Figure 5-35. Preference function for the least difficult to implement group

Case analysis results revision with long-term benefit and preference functions

Based upon evaluated long-term benefit probability distributions and corresponding preference functions, the advisory mode BBN case is analyzed again. The optimal action is identified with three criteria as discussed: 1) expected net benefit, 2) expected preference and 3) benefit to cost ratio.

1. **The expected net benefit criterion -** The action with the largest expected net benefit is the optimal action alternative. Figures 5-36 and 5-37 show that 'Hire additional resources' action is the optimal action in both the medium and the least difficult implement group cases.

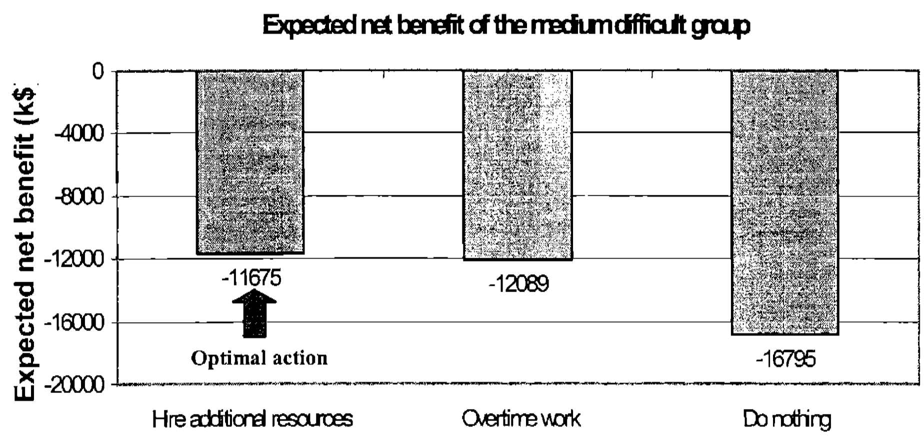


Figure 5-36. Optimal action with expected net benefit in the medium difficult group

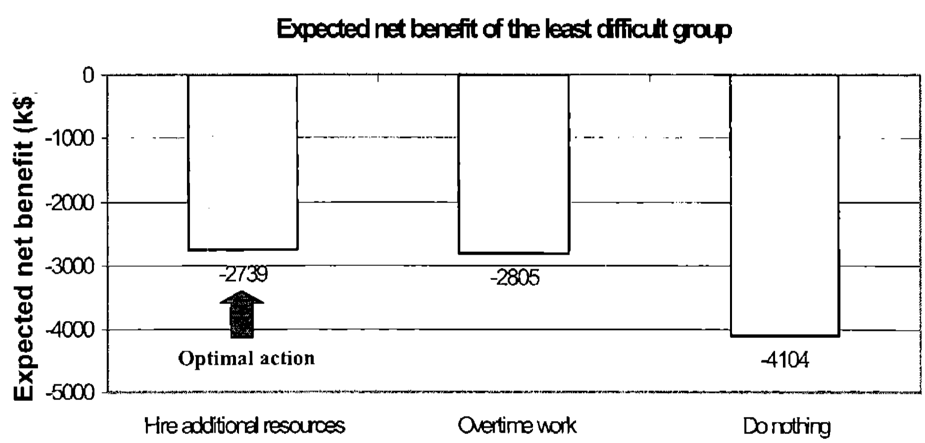


Figure 5-37. Optimal action with expected net benefit in the least difficult group

2. **The expected preference** – The action with the largest expected preference value is the optimal action alternative. As discussed in the previous section, the expected preference is the criterion considering the project performance and the decision maker's attitude to risk. The 'Hire additional resources' is the optimal action alternative in both the medium and the least difficult groups as shown in Figures 5-38 and 5-39.

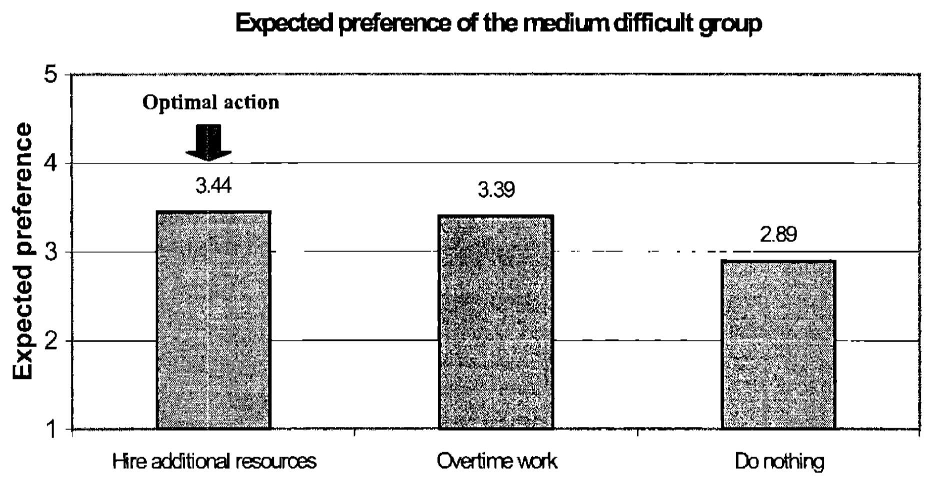


Figure 5-38. Optimal action with expected preference in the medium difficult group

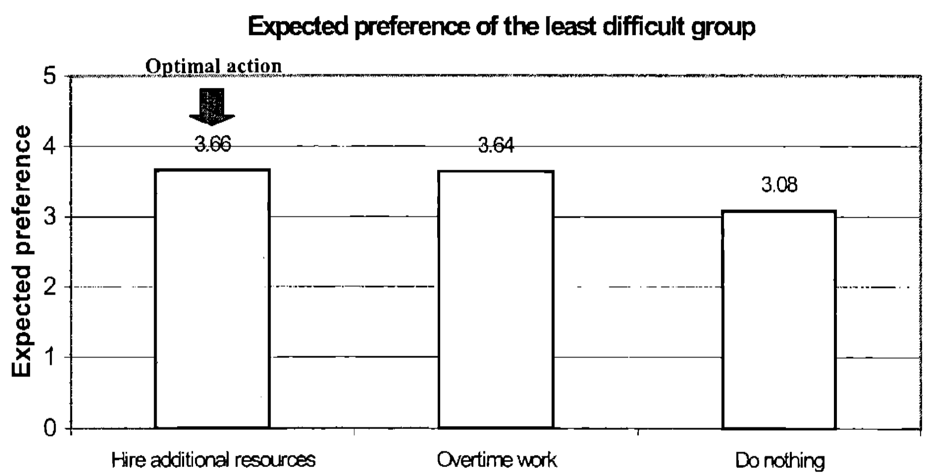


Figure 5-39. Optimal action with expected preference in the least difficult group

3. **The benefit to cost ratio** – The action with the largest benefit to cost ratio value is the optimal action. It should be noted that the benefit to cost ratio is not applicable to the action 'Do nothing' since this action has no cost, which means the benefit to cost ratio cannot be calculated. Under the benefit to cost ratio criterion, 'Hire additional resources' is the optimal action alternative in both groups as shown in Figures 5-40 and 5-41.

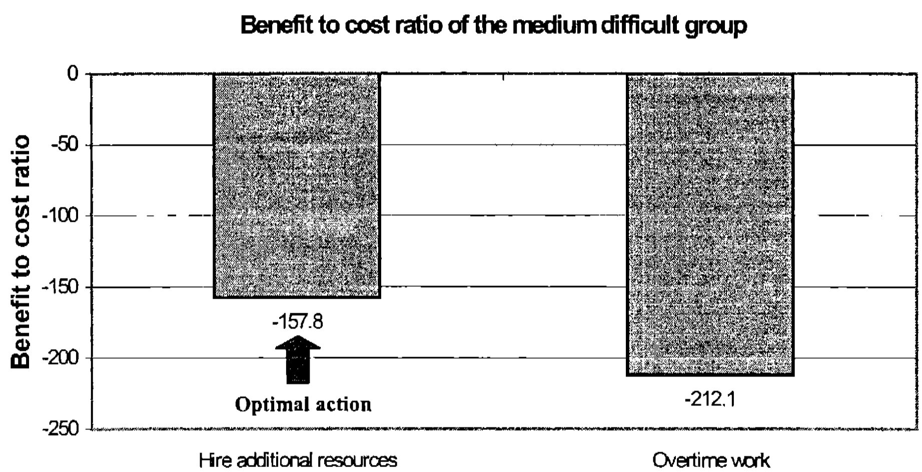


Figure 5-40. Optimal action with benefit to cost ratio in the medium difficult group

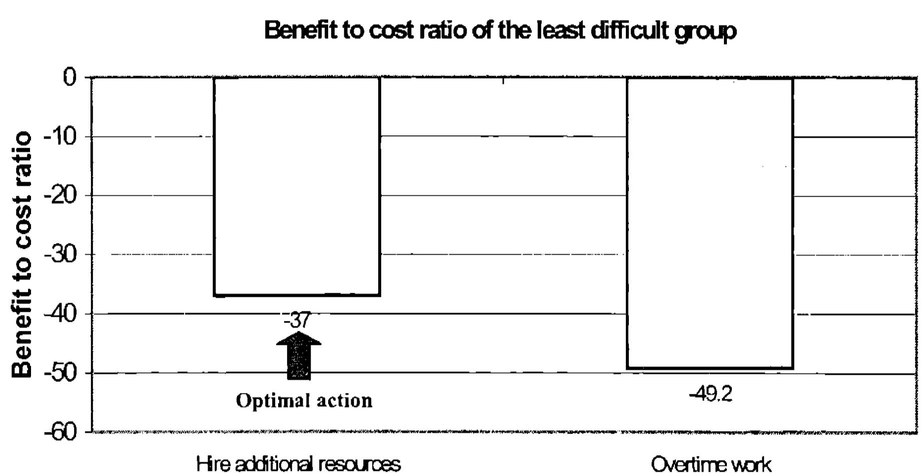


Figure 5-41. Optimal action with benefit to cost ratio in the least difficult group

5.3 Applicability of current advisory system to another field

As mentioned earlier, one of problems in the BBN approach is the very large number of conditional probability distributions for describing the strength of dependent relationships among variables. During the process of developing BBN models, obtaining the conditional probability distributions for variables is a very important step since those values govern the behavior of the BBN-based advisory system. In addition, the variables, structure and obtained corresponding conditional probability distributions in the models are likely to be problem specific. As a result, obtaining and adjusting conditional probability distributions are time consuming, slow and require very careful work and continuous iterative communications with domain experts. Therefore, the applicability of currently developed structure, variables and corresponding conditional probability distributions can be an issue when the developed advisory system is applied to other problems or when developing the same type of advisory system for other problems. The application area of the current advisory system in this work is a steam generator replacement project management. When the currently developed advisory system is applied to another problem, such as nuclear power plant construction projects or civil construction projects, all steps must be repeated from the very beginning if the level of applicability of currently developed models is not known. Then, it will take a long time and be very cumbersome work. If the level of applicability of current models (i.e., how many or which variables and corresponding conditional probability distributions can be applicable to other problems) is known, then much less time and effort is needed compared to starting from the very beginning. The purpose of this analysis is to identify the variables and corresponding conditional probabilities in currently developed models that can be used in other application fields and hence, to reduce the time and efforts in development of similar advisory systems in the future.

Questionnaire

1. Followings are the input and output variables considered in currently developed advisory system for steam generator replacement project management. For each variable, what is the possibility that a variable would be important in modeling if the current advisory system is applied to specified another area problem? Please enter the estimated possibility in the parenthesis corresponding each variable name below using the scale in Figure 5-42 at the end of this questionnaire.

For Nuclear Power Plant Construction Project

- Input variables
    1) Time ( )
    2) Cost ( )
    3) Quality ( )
    4) Scope ( )
    5) Client satisfaction ( )
    6) Human resource ( )
    7) Material resource ( )
- Output variables
    1) SPI (Schedule Performance Index) ( )
    2) CPI (Cost Performance Index) ( )

For Traditional Civil Construction Project

- Input variables
    1) Time ( )
    2) Cost ( )
    3) Quality ( )
    4) Scope ( )
    5) Client satisfaction ( )
    6) Human resource ( )
    7) Material resource ( )

- Output variables
  1) SPI (Schedule Performance Index) (   )
  2) CPI (Cost Performance Index) (   )

2. Following are the input and output variables considered in a currently developed advisory system for steam generator replacement project management. For each variable, the behaviors are described by corresponding conditional probability values. What is the confidence on those current conditional probability values for each variable can describe the behaviors properly if the current advisory system is applied to another area problem? Please enter the estimated confidence in the parenthesis corresponding each variable name using the scale in Figure 5-42.

For Nuclear Power Plant Construction Project

- Input variables
  1) Time (   )
  2) Cost (   )
  3) Quality (   )
  4) Scope (   )
  5) Client satisfaction (   )
  6) Human resource (   )
  7) Material resource (   )
- Output variables
  1) SPI (Schedule Performance Index) (   )
  1) CPI (Cost Performance Index) (   )

For Traditional Civil Construction Project

- Input variables
  1) Time (   )
  2) Cost (   )
  3) Quality (   )
  4) Scope (   )

5) Client satisfaction ( )
6) Human resource ( )
7) Material resource ( )

- Output variables

1) SPI (Schedule Performance Index) ( )
2) CPI (Cost Performance Index) ( )

3. Following are the management actions considered in a currently developed advisory system for steam generator replacement project management. For each management action, what is the possibility that an action would be important if the current advisory system is applied to another area problem? Please enter the estimated possibility in the parenthesis corresponding each action name below using the scale in Figure 5-42. In addition, if any other actions other than those listed below should be included, please specify them.

For Nuclear Power Plant Construction Project

1) Hire people from job market ( )
2) Hire people from contractor ( )
3) Overtime work ( )
4) Layoff people ( )
5) Resource transfer ( )
6) Scope change ( )
7) New technology introduction ( )
8) Equipment reduction ( )
9) Do nothing ( )

Actions should be included:

For Traditional Civil Construction Project

1) Hire people from job market ( )
2) Hire people from contractor ( )

3) Overtime work ( )
4) Layoff people ( )
5) Resource transfer ( )
6) Scope change ( )
7) New technology introduction ( )
8) Equipment reduction ( )
9) Do nothing ( )

Actions should be included:

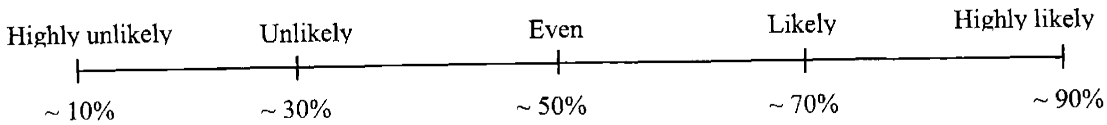


Figure 5-42. Possibility (or confidence) scale using the verbal terms

Survey results for applicability level of current model to other fields

This survey has been given to several human experts so the results in the following figures represent the average value of their answers. In this analysis, the weighted average approach is not selected because it is very difficult to determine the weight of each human expert. Therefore, it is assumed that every human expert has an equal weight to each other.

Levels of applicability of variables considered in the current model to another problem domain are shown in Figure 5-43 (nuclear power plant construction project) and in Figure 5-44 (traditional civil construction project). As expected, the level of applicability to nuclear power plant construction project shows a higher value than that of the civil project. This is because nuclear power plant construction has more similar aspects with the steam generator replacement work in the same nuclear field, which is the application problem of the current model. Four variables, time, cost, SPI and CPI show around 90% applicability because time and cost schedules are the factors that the project managers are concerned about most among all types of project: time and cost for input vs. SPI and CPI for output variables. The other variables (i.e., quality, scope, client satisfaction, human resource and material resource) show over 50% of applicability level in both problem domains.

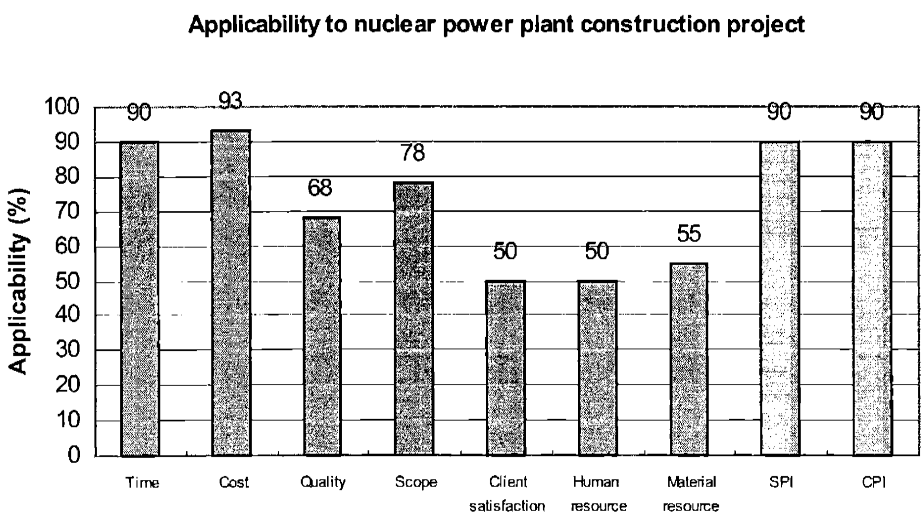


Figure 5-43. Applicability of variables to nuclear power plant construction project

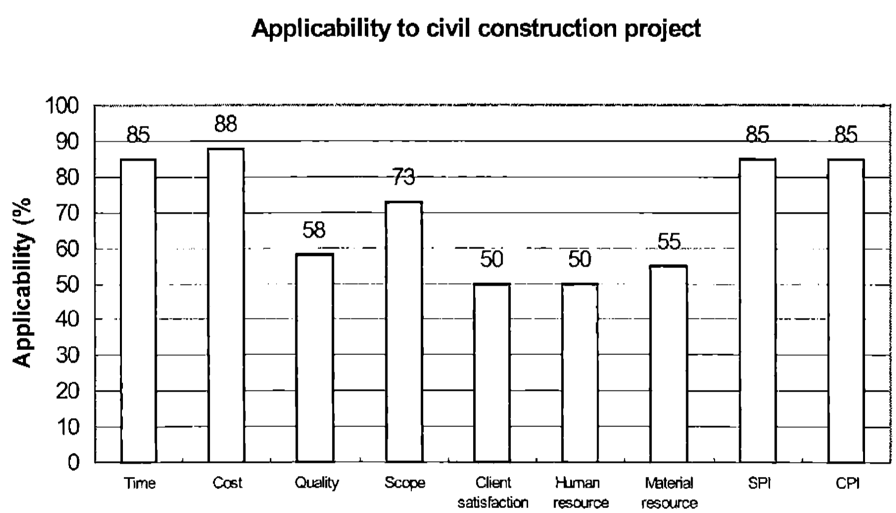


Figure 5-44. Applicability of variables to civil construction project

In both problem domains, the conditional probability values assigned to the current model can be used again with high confidence level, at least over 50% as seen in Figures 5-45 and 5-46. Like applicability of the variables case, the confidence level of current probability values show slightly higher in nuclear power plant construction than that of civil area due to more similar aspects. In addition, the confidence for time and cost schedule variables show higher level than for the other variables (i.e., quality, scope, client satisfaction, human resource and material resource).

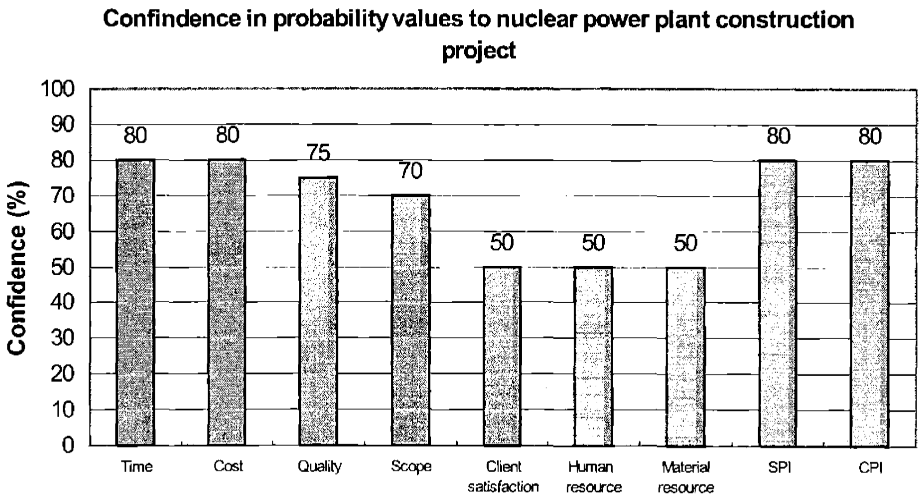


Figure 5-45. Confidence in probability values to nuclear power plant construction project

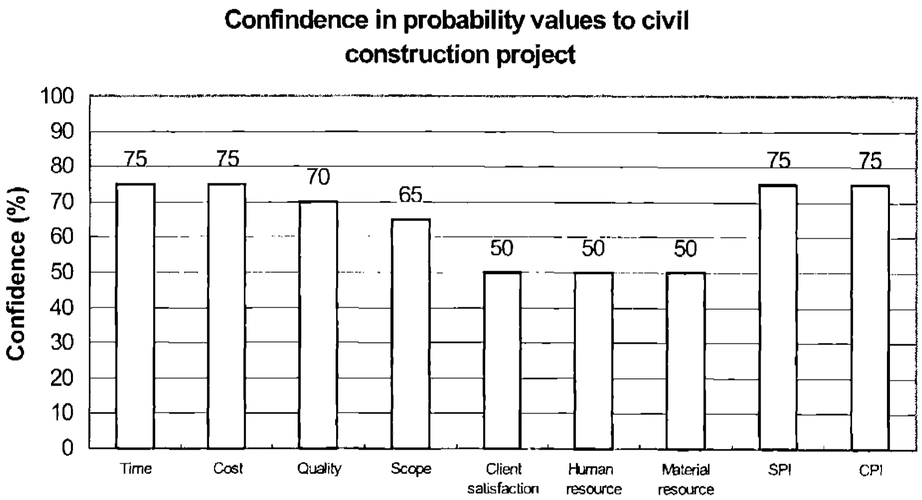


Figure 5-46. Confidence in probability values to civil construction project

All action alternatives considered in the current model show applicability levels over 50%, except 'New technology introduction'. Among them, the applicability levels for the action alternatives related to resources (i.e., human or material) appear high in both problem domains as seen in Figures 5-47 and 5-48: e.g., Hire from contractor, Overtime work, Layoff and Resource transfer. This is because most troubles in the project are from human or materials problems and hence, the action alternatives, which can work effectively and timely, are related to human or material. Note that 'Hire from job market' shows a lower value than 'Hire from contractor' since it takes more time for hiring effect on the project (more time to hire and more time to be familiar to work).

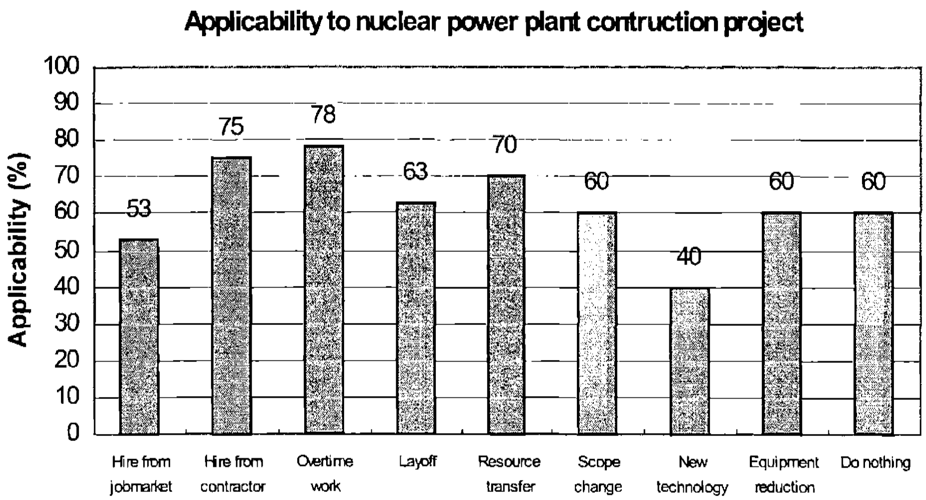


Figure 5-47. Applicability of actions to nuclear power plant construction project

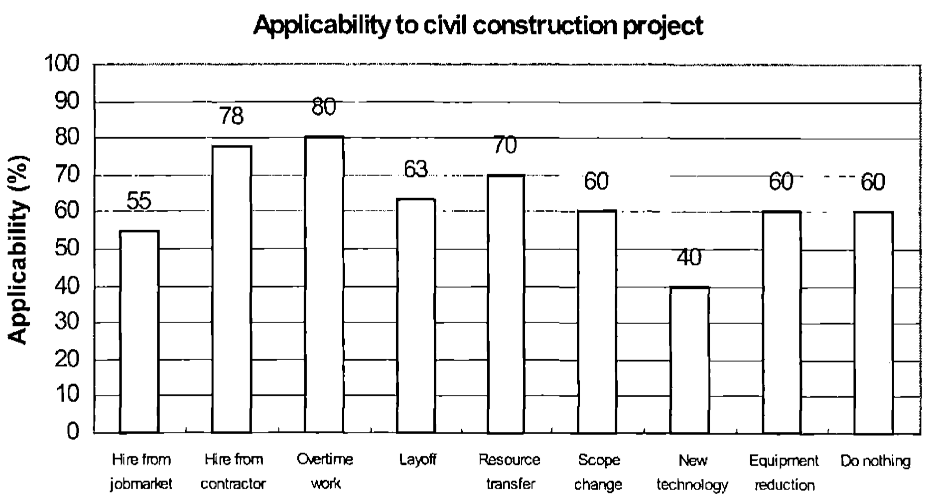


Figure 5-48. Applicability of actions to civil construction project

5.4 Uncertainty incorporation

Although the advisory system developed using the BBN approach considers many sources of uncertainty in project management problems, there are still remaining uncertainties unresolved, such as the uncertainty in the cost and benefit information and current evidence. The uncertainty in cost and benefit information is already incorporated in the current advisory system. As depicted in long-term benefit (or penalty) probability distributions, the uncertainty in cost and benefit information is expressed in the form of probability distributions and results in the expected average values (i.e., the immediate expected net benefit and the expected long-term benefit). Also, the current advisory system displays the resulting net benefit probability distributions.

For the uncertainty in current evidence, suppose one of the project performance indices shows a single value from the monitoring system. However, this value may not be 100% certain since there are many sources of uncertainties affecting the project performance index value, such as those in measurements of data, in entering the data into computer systems, in communications among other systems and so on. Therefore, there may be some possibilities that the true state of the performance index value is not that indicated (i.e., there might be a non-zero probability for other state values of the index). The best way to handle this issue is to express the current evidence in the form of a probability distribution function, as in the case of uncertainty in cost and benefit information. Table 5-13 shows one survey result concerning the uncertainties in our knowledge of the current evidence. It should be noted that this survey was conducted with domain experts, based upon the assumption of use of a very highly reliable monitoring system. This survey has been performed for three states of the project performance index as shown in Table 5-13: 1) Pessimistic case – index value in range of 0.6 ~ 0.8, 2) Neutral case – index value in range of 0.8 ~ 1.0 and 3) Optimistic case – index value in range of 1.0 ~ 1.2. For example, the Neutral case in Table 1 shows that there are probabilities of 5% for the other states of the index (i.e., 0.6 ~ 0.8 and 1.0 ~ 1.2) although the monitoring system indicates the index to be in state of 0.8 ~ 1.0 with very high reliability.

Table 5-13. Uncertainties in current evidence

Pessimistic case	Index state	0.6 ~ 0.8	0.8 ~ 1.0	1.0 ~ 1.2
	Probability	0.95	0.05	0
Neutral case	Index state	0.6 ~ 0.8	0.8 ~ 1.0	1.0 ~ 1.2
	Probability	0.05	0.9	0.05
Optimistic case	Index state	0.6 ~ 0.8	0.8 ~ 1.0	1.0 ~ 1.2
	Probability	0	0.05	0.95

Based upon the uncertainties of current evidence as shown in Table 5-13 and the 100% certain evidence value assumption (which was previously used in this work), the error bounds for the predictive mode BBN case example have been calculated again as seen in Figures 5-49 and 5-50. The size of the error bound in Figures 5-49 and 5-50 expresses the difference between two output project performances, resulting from two cases of current evidence: 1) the 100% certain current evidence case and 2) the uncertain current evidence case in Table 5-13. Due to the small uncertainty survey result for the current evidence, the error bounds in future project performance probability distributions are not large; the largest error bound size is around 0.02 (or 2%). However, the larger uncertainty in current evidence will result in the larger size error bounds in output project performance probability distributions. Also, these error bounds can be a measurement for the uncertainty in conditional probability values in the current BBN advisory system since the resultant project performance probability distributions already incorporate the uncertainty in conditional probability values. Note that the framework of incorporating uncertainty used here can be applied to all analysis results in this work and the predictive mode case example is selected as an example of how to apply this framework to other problems in this work.

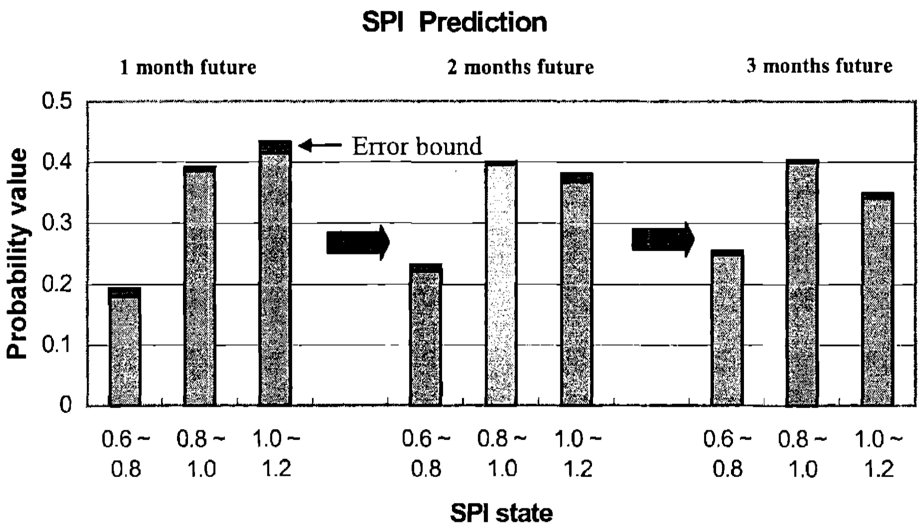


Figure 5-49. Error bound in SPI prediction probability distributions

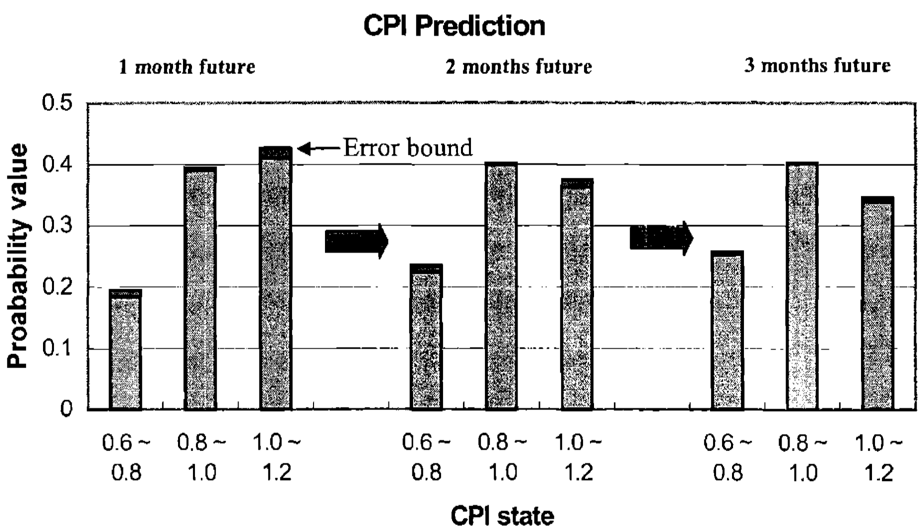


Figure 5-50. Error bound in CPI prediction probability distributions

As in the previous predictive mode case study, the mean values of project performance prediction probability distributions are computed and compared to real history values as seen in Figures 5-51 and 5-52. From the probability distributions, the maximum and minimum mean values can be computed for each time frame and the difference between these two values represents the size of uncertainties in the predictions. As described in Figures 5-51 and 5-52, the uncertainties from the current evidence and the conditional probability values are not large as seen in the small difference between the two curves (i.e., maximum and minimum prediction value curves) since the input uncertainty is not large as shown in Table 5-13. It should be noted that as time goes on, the discrepancy between the real value and the prediction value without management action increases as seen in Figures 5-51 and 5-52, because they represent different scenarios: with management action vs. no management action. However, the predictions with management action by advisory mode BBN in Figures 5-51 and 5-52 show good agreement with real values. It is believed that the project manager took action to restore SPI and CPI to normal value (i.e., 1.0) around 161 weeks, because the project performance shows behind schedule (i.e. SPI under 1.0) and over budget (i.e., CPI under 1.0) and the real value curve gets better from that time. Since there is no information on actions really taken, it is assumed that the project managers took an action of 'Hire more people' to restore project performance and the time duration needed to take effect was two months. Therefore, the prediction value curves with management action are computed by the predictive mode BBN from 156 to 161 weeks and by the advisory mode BBN from 161 to 169 weeks.

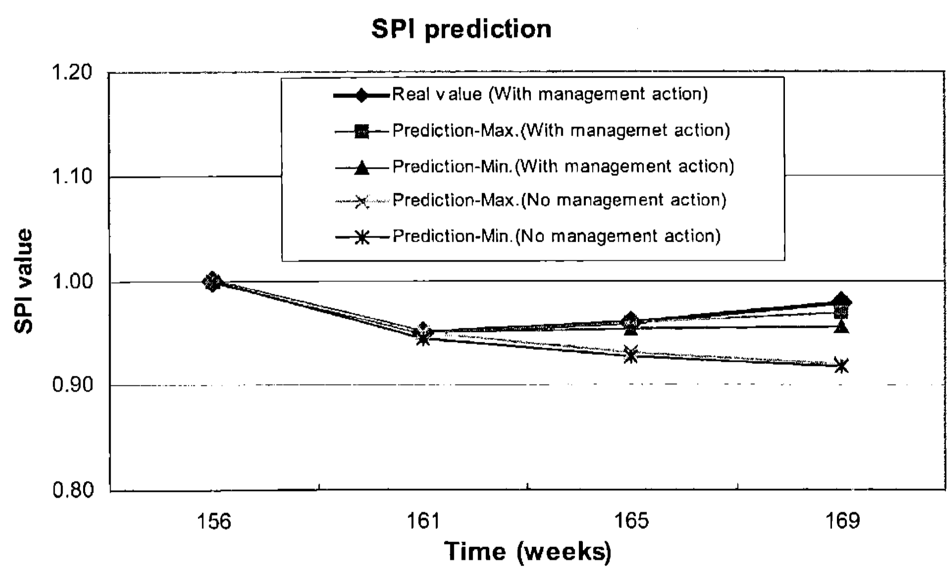


Figure 5-51. Uncertainty in SPI prediction in mean value of probability distribution

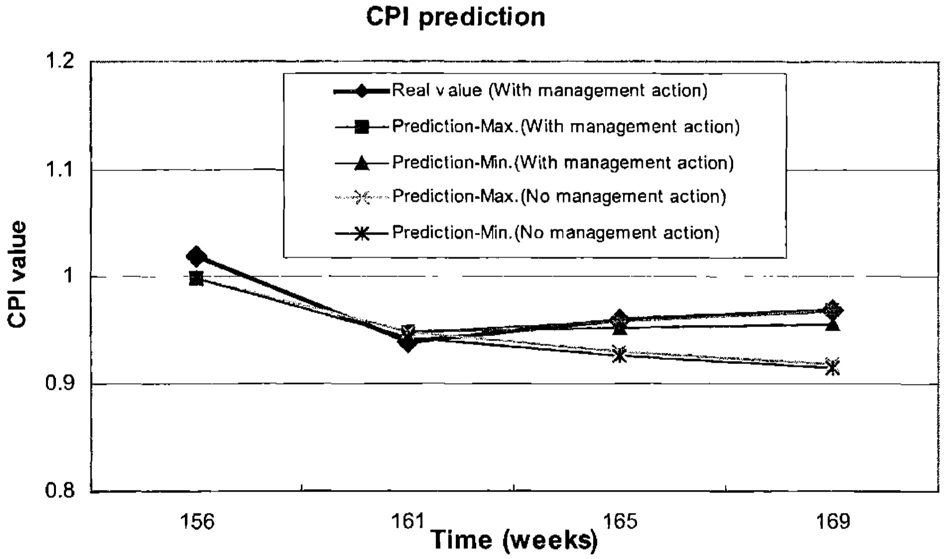


Figure 5-52. Uncertainty in CPI prediction in mean value of probability distribution

CHAPTER 6.
CONCLUSIONS AND FUTURE WORK

6.1 Conclusions

A BBN (Bayesian Belief Network)-based advisory system has been developed in this work. The system will help the Project Managers (PMs) especially in difficult decision-making situations and during the entire project lifetime as well, which is the steam generator replacement project that has been selected as an application problem. Based upon the literature survey and discussion with relevant experts, the conclusion is that the BBN approach is superior to artificial neural network or fuzzy-rule approaches in its ability to treat complexities, uncertainty management, systematic decision making, inference mechanism, knowledge representation and model modification for newly acquired knowledge. Therefore, the BBN approach was selected to model the steam generator replacement project management, where the situation holds inherently large uncertainty and complexities.

Different BBN models for the different work phases and the whole project lifetime have been constructed and integrated. During the thesis process, the communication with the domain experts has been iterated continuously to obtain and to program the expert knowledge base properly. For the BBN models, two modes of advisory system have been constructed for the above purposes. First mode, the predictive mode was developed, which can predict future project performance state probability distributions, assuming no any intervening management action. It is necessary to evaluate whether a future project performance state will be in good shape. If the bad project performances will be predicted in the near future, then the project manager should identify the problems and take proper action promptly to correct them. The second mode is the advisory mode that can identify the optimal action from alternatives based upon the expected net benefit values that incorporate two important components: 1) immediate expected net benefits at post-action time and 2) the expected long term benefit (or penalty) at scheduled project completion time. The long term benefit (or penalty) comes from the costs of the domino effect that originates from overdue provision of deliverables, lost reputation cost, and so on, which are not considered in the immediate benefit of an action taken. The full accurate costs and benefits of action alternatives (i.e., immediate net benefit and long term benefit (or penalty)) cannot be completely determined until the completion of the project since the time scale for evaluating an action is both short and long terms.

During the thesis work, the new indices for some of the identified important variables (i.e., cost, quality, scope, client satisfaction, human resources and material resources) have been newly developed for effective and efficient project status monitoring. With application of developed indices to the advisory system, the long-term benefit (or penalty) was found to be the most important factor in determining the optimal action by the project management during the decision-making process and domain experts confirmed this fact. As a result, the effort has been focused on incorporating the long-term benefit (or penalty) concept in order to provide more reliable and accurate advice to the project manager. Finding proper input factors in different BBN models for different work phases and entering evidence to them and finding corresponding updated outputs may be cumbersome tasks because there are many factors in many BBN models for a individual work phase and for overall project lifetime. In order to overcome these inconveniences and to facilitate the communication between the BBN models and the users, an interface program has been developed using the Visual Basic language.

With help of the interface programs, a developed advisory system has been benchmarked for both BBN modes (i.e., predictive and advisory modes) with two information sources: 1) real case data and 2) agreement of domain human experts. In the case of real case data, the results of the developed advisory system were compared to real case data. When it was not possible to obtain real case data for benchmarking, the domain human experts confirmed the results. The results of currently developed advisory system showed good agreement with either real case data or domain experts' opinions.

When the developed advisory system is applied to the nuclear power plants construction project, the project managers will be able to manage the work more effectively and efficiently because it enhances the control in time, costs, quality and reliability of the projects. Hence, one of the major elements of electricity cost, the capital cost of nuclear power plants will be reduced. As a result, the nuclear power plants will have more competitive power in the electricity market.

6.2 Future work

Future efforts should include the four items listed below. Theses are either extension of this thesis work or work needed to complete the efforts undertaken in this study.

First, we need more real case information for benchmarking the advisory system developed in this thesis work. For example, the advisory mode BBN has nine action alternatives but the benchmark has not been performed on the behaviors of all nine actions, only on three action alternatives, because of the insufficient real case data. Since the behavior of three action alternatives showed good agreement with real case data, it was concluded that the structure of BBN model and the conditional probability values for these three action alternatives are good. Nevertheless, more real case data is needed for benchmarking the behaviors of remaining action alternatives.

Second, it was found in this thesis work that the long-term benefit (or penalty) of taken action is the most important key factor in determining the optimal action during the management process. One of the components of long-term benefit (or penalty) is the reputation value, which is very intangible, difficult to estimate and a large part of the long-term benefit (or penalty). In this work, this reputation value has been evaluated through discussions with human experts in the project management domain who may not be experts in reputation and brand issues. Therefore, we believe that estimating this reputation value with brand-consulting firms can provide more reliable and accurate and decision-making processes.

Third, as discussed in the previous section, the ultimate goal of this work was the development of an advisory system for nuclear power plant construction project management. As a result of the advisory system application, it is anticipated that the reduction of the capital cost of nuclear power plant will result in the more competitive power in the electricity market. In order to achieve this ultimate goal, there is need of modification of currently developed advisory system whose application field is the steam generator replacement project management. It is believed that there will not be much need of modification since the applicability level is high as discussed in Section 5.3.

Lastly, continuous and extensive testing and validation of the advisory system are essential concerning the adequacy and completeness of our developed advisory system. In particular, real field tests are recommended to ensure the advisory system can perform as intended in the actual project management environment.

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APPENDIX A.

CONDITIONAL PROBABILITY TABLE (CPT) for TIME-DEPENDENT BEHAVIOR in THE 1-MONTH PREDICTIVE MODE BBN

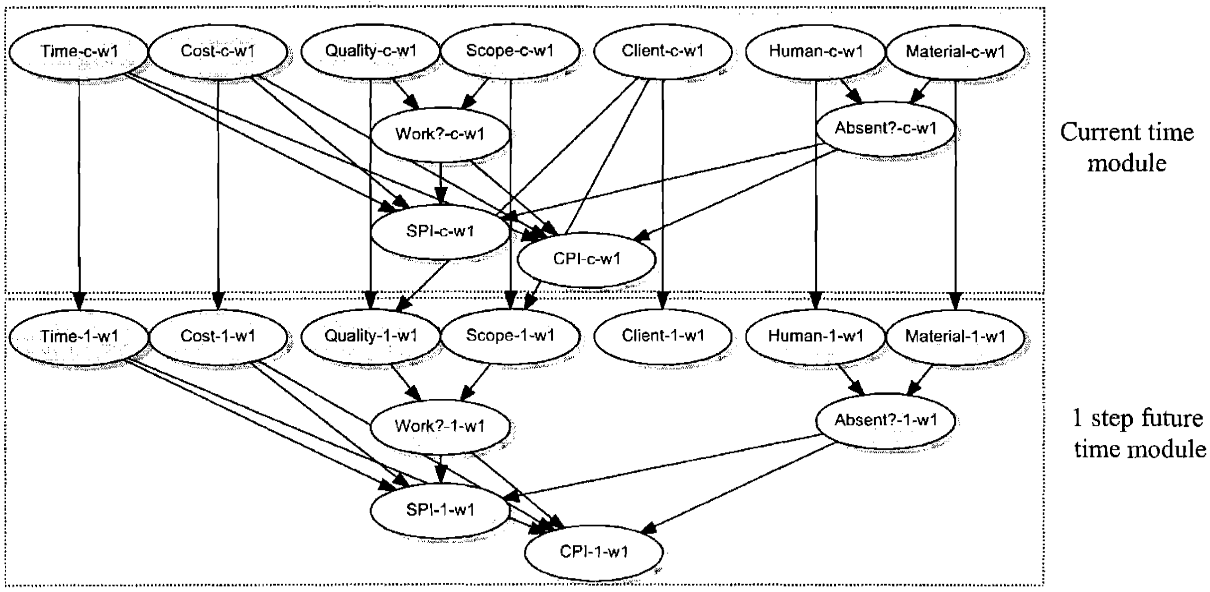

Figure A-1. The 1-month predictive mode BBN

Table A-1. CPTs for Time, Cost and Client satisfaction in 1 step future time module

	Time			Cost			Client satisfaction		
Cu. / Fu.	0.6-0.8	0.8-1.0	1.0-1.2	0.6-0.8	0.8-1.0	1.0-1.2	0.6-0.8	0.8-1.0	1.0-1.2
0.6-0.8	0.8	0.1	0.05	0.8	0.1	0.05	0.8	0.1	0.05
0.8-1.0	0.15	0.8	0.15	0.15	0.8	0.15	0.15	0.8	0.15
1.0-1.2	0.05	0.1	0.8	0.05	0.1	0.8	0.05	0.1	0.8

Cu.: Project performance state in the current time module

Fu.: Project performance state in the 1 step future time module

Table A-2. CPTs for Human resource and Material resource in 1 step future time module

	Human resource			Material resource		
Cu. / Fu.	0.6-0.8	0.8-1.0	1.0-1.2	0.6-0.8	0.8-1.0	1.0-1.2
0.6-0.8	0.8	0.1	0.05	0.8	0.1	0.05
0.8-1.0	0.15	0.8	0.15	0.15	0.8	0.15
1.0-1.2	0.05	0.1	0.8	0.05	0.1	0.8

Table A-3. CPT for Quality in 1 step future time module

Client*	0.6-0.8			0.8-1.0			1.0-1.2		
Quality*	0.6-0.8	0.8-1.0	1.0-1.2	0.6-0.8	0.8-1.0	1.0-1.2	0.6-0.8	0.8-1.0	1.0-1.2
0.6-0.8	0.7	0.4	0.2	0.6	0.1	0.3	0.2	0.4	0.1
0.8-1.0	0.2	0.5	0.6	0.3	0.8	0.5	0.7	0.4	0.2
1.0-1.2	0.1	0.1	0.2	0.1	0.1	0.2	0.1	0.2	0.7

Client*: Project performance state of Client satisfaction in the current time module

Quality*: Project performance state of Quality in the current time module

Table A-4. CPT for Scope in 1 step future time module

Client*	0.6-0.8			0.8-1.0			1.0-1.2		
Scope*	0.6-0.8	0.8-1.0	1.0-1.2	0.6-0.8	0.8-1.0	1.0-1.2	0.6-0.8	0.8-1.0	1.0-1.2
0.6-0.8	0.7	0.4	0.2	0.6	0.1	0.3	0.2	0.4	0.1
0.8-1.0	0.2	0.5	0.6	0.3	0.8	0.5	0.7	0.4	0.2
1.0-1.2	0.1	0.1	0.2	0.1	0.1	0.2	0.1	0.2	0.7

Client*: Project performance state of Client satisfaction in the current time module

Scope*: Project performance state of Scope in the current time module

APPENDIX B.

EXMAPLE VISUAL BASIC PROGRAMMING for THE PREDICTIVE MODE INTERFACE PRGRAM

```
Option Explicit
Dim d1, d2, d3, d4 As HAPI.Domain
Dim n As HAPI.Node
Dim file As Integer
Dim TimeP(1 To 3, 1 To 9), CostP(1 To 3, 1 To 9), ClientP(1 To 3, 1 To 9), HumanP(1 To 3, 1 To 9), MaterialP(1 To 3, 1 To 9) As
Single
Dim QualityP(1 To 3, 1 To 27), ScopeP(1 To 3, 1 To 27) As Single
Dim Tm1, Tm2, Tm3 As Integer
Dim EHOLD(1 To 3, 1 To 9) As Integer
Dim PriorPost As Integer
Dim parseErrors As Collection

 ' Define index for work unit 1 factors
Private Const Timecw1a = 0, Timecw1b = 1, Timecw1c = 2
Private Const Costcw1a = 0, Costcw1b = 1, Costcw1c = 2
Private Const Qualitycw1a = 0, Qualitycw1b = 1, Qualitycw1c = 2
Private Const Scopecw1a = 0, Scopecw1b = 1, Scopecw1c = 2
Private Const Clientcw1a = 0, Clientcw1b = 1, Clientcw1c = 2
Private Const Humancw1a = 0, Humancw1b = 1, Humancw1c = 2
Private Const Materialcw1a = 0, Materialcw1b = 1, Materialcw1c = 2
Private Const SPIcw1a = 0, SPIcw1b = 1, SPIcw1c = 2
Private Const CPIcw1a = 0, CPIcw1b = 1, CPIcw1c = 2

 ' Define index for work unit 2 factors
Private Const Timecw2a = 0, Timecw2b = 1, Timecw2c = 2
Private Const Costcw2a = 0, Costcw2b = 1, Costcw2c = 2
Private Const Qualitycw2a = 0, Qualitycw2b = 1, Qualitycw2c = 2
Private Const Scopecw2a = 0, Scopecw2b = 1, Scopecw2c = 2
Private Const Clientcw2a = 0, Clientcw2b = 1, Clientcw2c = 2
Private Const Humancw2a = 0, Humancw2b = 1, Humancw2c = 2
Private Const Materialcw2a = 0, Materialcw2b = 1, Materialcw2c = 2
Private Const SPIcw2a = 0, SPIcw2b = 1, SPIcw2c = 2
Private Const CPIcw2a = 0, CPIcw2b = 1, CPIcw2c = 2

 ' Define index for work unit 3factors
Private Const Timecw3a = 0, Timecw3b = 1, Timecw3c = 2
Private Const Costcw3a = 0, Costcw3b = 1, Costcw3c = 2
Private Const Qualitycw3a = 0, Qualitycw3b = 1, Qualitycw3c = 2
Private Const Scopecw3a = 0, Scopecw3b = 1, Scopecw3c = 2
Private Const Clientcw3a = 0, Clientcw3b = 1, Clientcw3c = 2
Private Const Humancw3a = 0, Humancw3b = 1, Humancw3c = 2
Private Const Materialcw3a = 0, Materialcw3b = 1, Materialcw3c = 2
Private Const SPIcw3a = 0, SPIcw3b = 1, SPIcw3c = 2
Private Const CPIcw3a = 0, CPIcw3b = 1, CPIcw3c = 2

 'Define index for overall project level SPI & CPI&EAC at 1-month future
Private Const SPI1oa = 0, SPI1ob = 1, SPI1oc = 2
Private Const CPI1oa = 0, CPI1ob = 1, CPI1oc = 2
'Private Const EAC1A = 0, EAC1B = 1
Private Const EAC1A = 1, EAC1B = 0

 'Define index for overall project level SPI & CPI&EAC at 2-month future
Private Const SPI2oa = 0, SPI2ob = 1, SPI2oc = 2
Private Const CPI2oa = 0, CPI2ob = 1, CPI2oc = 2
'Private Const EAC2A = 0, EAC2B = 1
Private Const EAC2A = 1, EAC2B = 0

 'Define index for overall project level SPI & CPI&EAC at 3-month future
Private Const SPI3oa = 0, SPI3ob = 1, SPI3oc = 2
Private Const CPI3oa = 0, CPI3ob = 1, CPI3oc = 2
Private Const EAC3A = 1, EAC3B = 0
```

```
Private Sub cdexit_Click()

 Call Form_Terminate

End Sub

Private Sub Clientcw1_Click(Index As Integer)

  'Get node name with name of CLIENT of work1 at current time
 If file = 1 Then
   Set n = d1.GetNodeByName("CLC1")
 ElseIf file = 2 Then
   Set n = d2.GetNodeByName("CLC1")
 ElseIf file = 3 Then
   Set n = d3.GetNodeByName("CLC1")
 ElseIf file = 4 Then
   Set n = d4.GetNodeByName("CLC1")
 End If
   'Enter the evidence to CLC1
    n.SelectState (Index)
    EHOLD(1, 5) = Index
End Sub

Private Sub Clientcw2_Click(Index As Integer)

  'Get node name with name of CLIENT of work2 at current time
 If file = 1 Then
   Set n = d1.GetNodeByName("CLC2")
 ElseIf file = 2 Then
   Set n = d2.GetNodeByName("CLC2")
 ElseIf file = 3 Then
   Set n = d3.GetNodeByName("CLC2")
 ElseIf file = 4 Then
   Set n = d4.GetNodeByName("CLC2")
 End If
   'Enter the evidence to CLC2
   n.SelectState (Index)
   EHOLD(2, 5) = Index
End Sub

Private Sub Clientcw3_Click(Index As Integer)

  'Get node name with name of CLIENT of work3 at current time
 If file = 1 Then
   Set n = d1.GetNodeByName("CLC3")
 ElseIf file = 2 Then
   Set n = d2.GetNodeByName("CLC3")
 ElseIf file = 3 Then
   Set n = d3.GetNodeByName("CLC3")
 ElseIf file = 4 Then
   Set n = d4.GetNodeByName("CLC3")
 End If
   'Enter the evidence to CLC3
   n.SelectState (Index)
   EHOLD(3, 5) = Index
End Sub

Private Sub Clearbutton()

 Dim i As Integer

   ' Intialize the option button in evidence selection section
  For i = 0 To 2
   Timecw1(i).Value = False
   Costcw1(i).Value = False
   Qualitycw1(i).Value = False
   Scopecw1(i).Value = False
   Clientcw1(i).Value = False
   Humancw1(i).Value = False
```

```
    Materialcw1(i).Value = False
    CPIcw1(i).Value = False
    SPIcw1(i).Value = False

    Timecw2(i).Value = False
    Costcw2(i).Value = False
    Qualitycw2(i).Value = False
    Scopecw2(i).Value = False
    Clientcw2(i).Value = False
    Humancw2(i).Value = False
    Materialcw2(i).Value = False
    CPIcw2(i).Value = False
    SPIcw2(i).Value = False

    Timecw3(i).Value = False
    Costcw3(i).Value = False
    Qualitycw3(i).Value = False
    Scopecw3(i).Value = False
    Clientcw3(i).Value = False
    Humancw3(i).Value = False
    Materialcw3(i).Value = False
    CPIcw3(i).Value = False
    SPIcw3(i).Value = False

  Next i

End Sub

Private Sub Clearbar()

    'Clear the bar graph
    SPI1A.Cls
    SPI1B.Cls
    SPI1C.Cls
    CPI1A.Cls
    CPI1B.Cls
    CPI1C.Cls
    SPI2A.Cls
    SPI2B.Cls
    SPI2C.Cls
    CPI2A.Cls
    CPI2B.Cls
    CPI2C.Cls
    SPI3A.Cls
    SPI3B.Cls
    SPI3C.Cls
    CPI3A.Cls
    CPI3B.Cls
    CPI3C.Cls

End Sub

Private Sub Costcw1_Click(Index As Integer)

   'Get node name with name of Cost of work1 at current time
  If file = 1 Then
    Set n = d1.GetNodeByName("CC1")
  ElseIf file = 2 Then
    Set n = d2.GetNodeByName("CC1")
  ElseIf file = 3 Then
    Set n = d3.GetNodeByName("CC1")
  ElseIf file = 4 Then
    Set n = d4.GetNodeByName("CC1")
  End If
    'Enter the evidence to CC1
    n.SelectState (Index)
    EHOLD(1, 2) = Index
End Sub

Private Sub Costcw2_Click(Index As Integer)
```

```
  'Get node name with name of Cost of work2 at current time
 If file = 1 Then
   Set n = d1.GetNodeByName("CC2")
 ElseIf file = 2 Then
   Set n = d2.GetNodeByName("CC2")
 ElseIf file = 3 Then
   Set n = d3.GetNodeByName("CC2")
 ElseIf file = 4 Then
   Set n = d4.GetNodeByName("CC2")
 End If
   'Enter the evidence to CC2
  n.SelectState (Index)
   EHOLD(2, 2) = Index
End Sub

Private Sub Costcw3_Click(Index As Integer)

  'Get node name with name of Cost of work3 at current time
 If file = 1 Then
   Set n = d1.GetNodeByName("CC3")
 ElseIf file = 2 Then
   Set n = d2.GetNodeByName("CC3")
 ElseIf file = 3 Then
   Set n = d3.GetNodeByName("CC3")
 ElseIf file = 4 Then
   Set n = d4.GetNodeByName("CC3")
 End If
   'Enter the evidence to CC3
  n.SelectState (Index)
   EHOLD(3, 2) = Index
End Sub

Private Sub CPIcw1_Click(Index As Integer)

  'Get node name with name of CPI of work1 at current time
 If file = 1 Then
   Set n = d1.GetNodeByName("CPIC1")
 ElseIf file = 2 Then
   Set n = d2.GetNodeByName("CPIC1")
 ElseIf file = 3 Then
   Set n = d3.GetNodeByName("CPIC1")
 ElseIf file = 4 Then
   Set n = d4.GetNodeByName("CPIC1")
 End If
   'Enter the evidence to CPIC1
  n.SelectState (Index)
   EHOLD(1, 9) = Index
End Sub

Private Sub CPIcw2_Click(Index As Integer)

  'Get node name with name of CPI of work2 at current time
 If file = 1 Then
   Set n = d1.GetNodeByName("CPIC2")
 ElseIf file = 2 Then
   Set n = d2.GetNodeByName("CPIC2")
 ElseIf file = 3 Then
   Set n = d3.GetNodeByName("CPIC2")
 ElseIf file = 4 Then
   Set n = d4.GetNodeByName("CPIC2")
 End If

   'Enter the evidence to CPIC2
  n.SelectState (Index)
   EHOLD(2, 9) = Index
End Sub

Private Sub CPIcw3_Click(Index As Integer)
```

```
 'Get node name with name of CPI of work3 at current time
 If file = 1 Then
  Set n = d1.GetNodeByName("CPIC3")
 ElseIf file = 2 Then
  Set n = d2.GetNodeByName("CPIC3")
 ElseIf file = 3 Then
  Set n = d3.GetNodeByName("CPIC3")
 ElseIf file = 4 Then
  Set n = d4.GetNodeByName("CPIC3")
 End If
  'Enter the evidence to CPIC3
 n.SelectState (Index)
  EHOLD(3, 9) = Index
End Sub

Private Sub Form_Load()

  Dim i, j, Tsave1, Tsave2, Tsave3 As Integer
  Dim parseErrors As Collection

  For i = 1 To 3
   For j = 1 To 9
    EHOLD(i, j) = 10
   Next j
  Next i

  preconcri.Enabled = False
  predetcri.Enabled = True
  prewpcri.Enabled = True
  presccri.Enabled = True
  preoutcri.Enabled = True

  Evidence.Caption = "Enter the Current Evidence (Conceptual Design Phase)"
  work2.Caption = "Work Group 1"
  work3.Caption = "Work Group 2"

  file = 1  'Give the index for which file is open, 1 means Conceptual design predictive mode file is open
  PriorPost = 0

 Call Clearbutton
 Call Unseenbutton
 Call Clearbar
 Call showoption

  ' Load the domain from the Hugin net file and compile it.
  Set d1 = HAPI.LoadDomainFromNet("C:\Hugin\cdpre3cr.net", parseErrors, -1)
  d1.Compile

  future1L.Caption = Tm1 & "-Month Future"
  future2L.Caption = Tm2 & "-Month Future"
  future3L.Caption = Tm3 & "-Month Future"

  future1S.Value = Tm1
  future2S.Value = Tm2
  future3S.Value = Tm3

  fu1L.Caption = Tm1
  fu2L.Caption = Tm2
  fu3L.Caption = Tm3

  Call showresult(file, 0)

End Sub

Private Sub Form_Terminate()

 Unload Me

End Sub
```

```
Private Sub future1S_Change()

fu1L.Caption = future1S.Value
futureT1 = future1S.Value

End Sub

Private Sub future2S_Change()

fu2L.Caption = future2S.Value
futureT2 = future2S.Value

End Sub

Private Sub future3S_Change()

fu3L.Caption = future3S.Value
futureT3 = future3S.Value

End Sub

Private Sub gotoadv_Click()

   If file = 1 Then
     d1.Delete
   ElseIf file = 2 Then
     d2.Delete
   ElseIf file = 3 Then
     d3.Delete
   ElseIf file = 4 Then
      d4.Delete
   End If

  frmadv.Show
  Unload Me

End Sub

Private Sub Humancw1_Click(Index As Integer)

  'Get node name with name of HUMAN of work1 at current time
 If file = 1 Then
  Set n = d1.GetNodeByName("HC1")
 ElseIf file = 2 Then
  Set n = d2.GetNodeByName("HC1")
 ElseIf file = 3 Then
  Set n = d3.GetNodeByName("HC1")
 ElseIf file = 4 Then
  Set n = d4.GetNodeByName("HC1")
 End If
  'Enter the evidence to HC1
  n.SelectState (Index)
   EHOLD(1, 6) = Index
End Sub

Private Sub Humancw2_Click(Index As Integer)

  'Get node name with name of HUMAN of work2 at current time
 If file = 1 Then
  Set n = d1.GetNodeByName("HC2")
 ElseIf file = 2 Then
  Set n = d2.GetNodeByName("HC2")
 ElseIf file = 3 Then
  Set n = d3.GetNodeByName("HC2")
 ElseIf file = 4 Then
  Set n = d4.GetNodeByName("HC2")
 End If
  'Enter the evidence to HC2
  n.SelectState (Index)
   EHOLD(2, 6) = Index
```

```
End Sub

Private Sub Humancw3_Click(Index As Integer)

  'Get node name with name of HUMAN of work3 at current time
 If file = 1 Then
  Set n = d1.GetNodeByName("HC3")
 ElseIf file = 2 Then
  Set n = d2.GetNodeByName("HC3")
 ElseIf file = 3 Then
  Set n = d3.GetNodeByName("HC3")
 ElseIf file = 4 Then
  Set n = d4.GetNodeByName("HC3")
 End If
  'Enter the evidence to HC3
  n.SelectState (Index)
   EHOLD(3, 6) = Index
End Sub

Private Sub initialize_Click()

 Dim i, j As Integer

  Call Clearbutton
  Call Clearbar
  PriorPost = 0

   For i = 1 To 3
    For j = 1 To 9
     EHOLD(i, j) = 10
    Next j
   Next i

 If file = 1 Then
   d1.Initialize
   Call showresult(file, 0)
 ElseIf file = 2 Then
   d2.Initialize
    Call showresult(file, 0)
 ElseIf file = 3 Then
   d3.Initialize
   Call showresult(file, 0)
 ElseIf file = 4 Then
   d4.Initialize
   Call showresult(file, 0)
 End If

End Sub

Private Sub Materialcw1_Click(Index As Integer)

  'Get node name with name of MATERIAL of work1 at current time
 If file = 1 Then
  Set n = d1.GetNodeByName("MC1")
 ElseIf file = 2 Then
  Set n = d2.GetNodeByName("MC1")
 ElseIf file = 3 Then
  Set n = d3.GetNodeByName("MC1")
 ElseIf file = 4 Then
  Set n = d4.GetNodeByName("MC1")
 End If
  'Enter the evidence to MC1
  n.SelectState (Index)
  EHOLD(1, 7) = Index
End Sub

Private Sub Materialcw2_Click(Index As Integer)

  'Get node name with name of MATERIAL of work2 at current time
 If file = 1 Then
```

```
   Set n = d1.GetNodeByName("MC2")
  ElseIf file = 2 Then
   Set n = d2.GetNodeByName("MC2")
  ElseIf file = 3 Then
   Set n = d3.GetNodeByName("MC2")
  ElseIf file = 4 Then
   Set n = d4.GetNodeByName("MC2")
  End If
   'Enter the evidence to MC2
   n.SelectState (Index)
   EHOLD(2, 7) = Index
End Sub

Private Sub Materialcw3_Click(Index As Integer)

  'Get node name with name of MATERIAL of work3 at current time
  If file = 1 Then
   Set n = d1.GetNodeByName("MC3")
  ElseIf file = 2 Then
   Set n = d2.GetNodeByName("MC3")
  ElseIf file = 3 Then
   Set n = d3.GetNodeByName("MC3")
  ElseIf file = 4 Then
   Set n = d4.GetNodeByName("MC3")
  End If
   'Enter the evidence to MC3
  n.SelectState (Index)
  EHOLD(3, 7) = Index
End Sub

Private Sub menchange_Click()

Dim i, T1, T2, T3 As Integer

T1 = futureT1
T2 = futureT2 - futureT1
T3 = futureT3 - futureT2

If T2 <= 0 Or T3 <= 0 Then
   MsgBox "PLEASE ENTER IN INCREASING ORDER !!", , "WARNING !!"
Else

future1L.Caption = futureT1 & "-Month Future"
future2L.Caption = futureT2 & "-Month Future"
future3L.Caption = futureT3 & "-Month Future"

Tm1 = futureT1
Tm2 = futureT2
Tm3 = futureT3

Call Clearbar
    If file = 1 Then
      Call d1.Propagate(HAPI.hEquilibriumSum, HAPI.hModeNormal)
    ElseIf file = 2 Then
      Call d2.Propagate(HAPI.hEquilibriumSum, HAPI.hModeNormal)
    ElseIf file = 3 Then
      Call d3.Propagate(HAPI.hEquilibriumSum, HAPI.hModeNormal)
    ElseIf file = 4 Then
      Call d4.Propagate(HAPI.hEquilibriumSum, HAPI.hModeNormal)
    End If

 If PriorPost = 0 Then
   Call showresult(file, 0)
 ElseIf PriorPost = 1 Then
  Call showresult(file, 1)
 End If

End If

End Sub
```

```
Private Sub meninitialize_Click()

 Call initialize_Click

End Sub

Private Sub menupdate_Click()

 Call Update_Click

End Sub

Private Sub Pover_Click()

   If file = 1 Then
      d1.Delete
   ElseIf file = 2 Then
      d2.Delete
   ElseIf file = 3 Then
      d3.Delete
   ElseIf file = 4 Then
       d4.Delete
   End If

  overall.Show
  Unload Me

End Sub

Private Sub preconcri_Click()

   Dim i, Tsave1, Tsave2, Tsave3 As Integer

   preconcri.Enabled = False
   predetcri.Enabled = True
   prewpcri.Enabled = True
   presccri.Enabled = True
   preoutcri.Enabled = True

     'Delete the other files
   If file = 2 Then
      d2.Delete
   ElseIf file = 3 Then
      d3.Delete
   ElseIf file = 4 Then
      d4.Delete
   End If

  work2.Caption = "Work Group 1"
  work3.Caption = "Work Group 2"
  Evidence.Caption = "Enter the Current Evidence (Conceptual Design Phase)"

   If file <> 1 Then
     Set d1 = HAPI.LoadDomainFromNet("C:\Hugin\cdpre3cr.net", parseErrors, -1)
     d1.Compile
   End If

  file = 1  'Give the index for which file is open, 1 means Conceptual design predictive mode file is open
  PriorPost = 0

   Call Clearbutton
   Call Unseenbutton
   Call Clearbar
   Call showoption

   Tm1 = 1
   Tm2 = 2
   Tm3 = 3
```

```
  future1L.Caption = Tm1 & "-Month Future"
  future2L.Caption = Tm2 & "-Month Future"
  future3L.Caption = Tm3 & "-Month Future"

  future1S.Value = Tm1
  future2S.Value = Tm2
  future3S.Value = Tm3
  fu1L.Caption = Tm1
  fu2L.Caption = Tm2
  fu3L.Caption = Tm3

 Call showresult(file, 0)

End Sub

Private Sub predetcri_Click()

  Dim i, Tsave1, Tsave2, Tsave3 As Integer

  preconcri.Enabled = True
  predetcri.Enabled = False
  prewpcri.Enabled = True
  presccri.Enabled = True
  preoutcri.Enabled = True

   'Delete the other files
  If file = 1 Then
    d1.Delete
  ElseIf file = 3 Then
    d3.Delete
  ElseIf file = 4 Then
    d4.Delete
  End If

 work2.Caption = "Work Group 1"
 work3.Caption = "Work Group 2"
 Evidence.Caption = "Enter the Current Evidence (Detailed Design Phase)"

  ' Load the domain from the Hugin net file and compile it.
  If file <> 2 Then
    Set d2 = HAPI.LoadDomainFromNet("C:\Hugin\ddpre3cr.net", parseErrors, -1)
    d2.Compile
  End If

  file = 2  'Give the index for which file is open, 2 means Detailed design predictive mode file is open
 PriorPost = 0

 Call Clearbutton
 Call Clearbar
 Call Unseenbutton
 Call showoption

  Tm1 = 1
  Tm2 = 2
  Tm3 = 3

 future1L.Caption = Tm1 & "-Month Future"
 future2L.Caption = Tm2 & "-Month Future"
 future3L.Caption = Tm3 & "-Month Future"

 future1S.Value = Tm1
 future2S.Value = Tm2
 future3S.Value = Tm3
 fu1L.Caption = Tm1
 fu2L.Caption = Tm2
 fu3L.Caption = Tm3

 Call showresult(file, 0)

End Sub
```

```
Private Sub preoutcri_Click()

   Dim i, Tsave1, Tsave2, Tsave3 As Integer
   preconcri.Enabled = True
   predetcri.Enabled = True
   prewpcri.Enabled = True
   presccri.Enabled = True
   preoutcri.Enabled = False

    'Delete the other files
   If file = 1 Then
      d1.Delete
   ElseIf file = 2 Then
      d2.Delete
   ElseIf file = 3 Then
      d3.Delete
   End If

  Evidence.Caption = "Enter the Current Evidence (Outage Phase)"
   work1.Caption = "Work Group 1"
   work2.Caption = "Work Group 2"
   work3.Caption = "Work Group 3"

    ' Load the domain from the Hugin net file and compile it.
   If file <> 4 Then
      Set d4 = HAPI.LoadDomainFromNet("C:\Hugin\siteoutpre3cr.net", parseErrors, -1)
      d4.Compile
   End If
   file = 4  'Give the index for which file is open, 4 means Outage predictive mode file is open
  PriorPost = 0

  Call Clearbutton
  Call Unseenbutton
  Call Clearbar
  Call showoption

   Tm1 = 1
   Tm2 = 2
   Tm3 = 3

   future1L.Caption = Tm1 & "-Month Future"
   future2L.Caption = Tm2 & "-Month Future"
   future3L.Caption = Tm3 & "-Month Future"

   future1S.Value = Tm1
   future2S.Value = Tm2
   future3S.Value = Tm3

   fu1L.Caption = Tm1
   fu2L.Caption = Tm2
   fu3L.Caption = Tm3

  Call showresult(file, 0)

End Sub

Private Sub presccri_Click()

   Dim i, Tsave1, Tsave2, Tsave3 As Integer

   preconcri.Enabled = True
   predetcri.Enabled = True
   prewpcri.Enabled = True
   presccri.Enabled = False
   preoutcri.Enabled = True

    'Delete the other files
   If file = 1 Then
      d1.Delete
```

```
  ElseIf file = 2 Then
     d2.Delete
  ElseIf file = 3 Then
     d3.Delete
  End If

 Evidence.Caption = "Enter the Current Evidence (Site && Craft Mobilization Phase)"
 work1.Caption = "Work Group 1"
 work2.Caption = "Work Group 2"
 work3.Caption = "Work Group 3"

   ' Load the domain from the Hugin net file and compile it.
 If file <> 4 Then
    Set d4 = HAPI.LoadDomainFromNet("C:\Hugin\siteoutpre3cr.net", parseErrors, -1)
    d4.Compile
 End If

 file = 4  'Give the index for which file is open, 4 means Site & Craft Mobilization predictive mode file is open
 PriorPost = 0

 Call Clearbutton
 Call Clearbar
 Call Unseenbutton
 Call showoption

  Tm1 = 1
  Tm2 = 2
  Tm3 = 3

 future1L.Caption = Tm1 & "-Month Future"
 future2L.Caption = Tm2 & "-Month Future"
 future3L.Caption = Tm3 & "-Month Future"

 future1S.Value = Tm1
 future2S.Value = Tm2
 future3S.Value = Tm3

 fu1L.Caption = Tm1
 fu2L.Caption = Tm2
 fu3L.Caption = Tm3

 Call showresult(file, 0)

End Sub

Private Sub prewpcri_Click()
  Dim i, Tsave1, Tsave2, Tsave3 As Integer
  preconcri.Enabled = True
  predetcri.Enabled = True
  prewpcri.Enabled = False
  presccri.Enabled = True
  preoutcri.Enabled = True

   'Delete the other files
  If file = 1 Then
     d1.Delete
  ElseIf file = 2 Then
     d2.Delete
  ElseIf file = 4 Then
     d4.Delete
  End If

 Evidence.Caption = "Enter the Current Evidence (Work Package Develpment Phase)"
 work2.Caption = "Work Group 1"
 work3.Caption = "Work Group 2"

   ' Load the domain from the Hugin net file and compile it.
  If file <> 3 Then
    Set d3 = HAPI.LoadDomainFromNet("C:\Hugin\wppre3cr.net", parseErrors, -1)
    d3.Compile
```

```
  End If

  file = 3  'Give the index for which file is open, 3 means Work Package Development predictive mode file is open
 PriorPost = 0

 Call Clearbutton
 Call Clearbar
 Call Unseenbutton
 Call showoption

  Tm1 = 1
  Tm2 = 2
  Tm3 = 3

 future1L.Caption = Tm1 & "-Month Future"
 future2L.Caption = Tm2 & "-Month Future"
 future3L.Caption = Tm3 & "-Month Future"

 future1S.Value = Tm1
 future2S.Value = Tm2
 future3S.Value = Tm3
 fu1L.Caption = Tm1
 fu2L.Caption = Tm2
 fu3L.Caption = Tm3

 Call showresult(file, 0)

End Sub

Private Sub Qualitycw1_Click(Index As Integer)

  'Get node name with name of Quality of work1 at current time
 If file = 1 Then
  Set n = d1.GetNodeByName("QC1")
 ElseIf file = 2 Then
  Set n = d2.GetNodeByName("QC1")
 ElseIf file = 3 Then
  Set n = d3.GetNodeByName("QC1")
 ElseIf file = 4 Then
  Set n = d4.GetNodeByName("QC1")
 End If
  'Enter the evidence to QC1
  n.SelectState (Index)
  EHOLD(1, 3) = Index

End Sub

Private Sub Qualitycw2_Click(Index As Integer)

  'Get node name with name of Quality of work2 at current time
 If file = 1 Then
  Set n = d1.GetNodeByName("QC2")
 ElseIf file = 2 Then
  Set n = d2.GetNodeByName("QC2")
 ElseIf file = 3 Then
  Set n = d3.GetNodeByName("QC2")
 ElseIf file = 4 Then
  Set n = d4.GetNodeByName("QC2")
 End If
  'Enter the evidence to QC2
  n.SelectState (Index)
  EHOLD(2, 3) = Index
End Sub

Private Sub Qualitycw3_Click(Index As Integer)

  'Get node name with name of Quality of work3 at current time
 If file = 1 Then
  Set n = d1.GetNodeByName("QC3")
 ElseIf file = 2 Then
```

```
  Set n = d2.GetNodeByName("QC3")
 ElseIf file = 3 Then
  Set n = d3.GetNodeByName("QC3")
 ElseIf file = 4 Then
  Set n = d4.GetNodeByName("QC3")
 End If
  'Enter the evidence to QC3
 n.SelectState (Index)
 EHOLD(3, 3) = Index
End Sub

Private Sub Scopecw1_Click(Index As Integer)

  'Get node name with name of SCOPE of work1 at current time
 If file = 1 Then
  Set n = d1.GetNodeByName("SC1")
 ElseIf file = 2 Then
  Set n = d2.GetNodeByName("SC1")
 ElseIf file = 3 Then
  Set n = d3.GetNodeByName("SC1")
 ElseIf file = 4 Then
  Set n = d4.GetNodeByName("SC1")
 End If
  'Enter the evidence to SC1
 n.SelectState (Index)
 EHOLD(1, 4) = Index
End Sub

Private Sub Scopecw2_Click(Index As Integer)

  'Get node name with name of SCOPE of work2 at current time
 If file = 1 Then
  Set n = d1.GetNodeByName("SC2")
 ElseIf file = 2 Then
  Set n = d2.GetNodeByName("SC2")
 ElseIf file = 3 Then
  Set n = d3.GetNodeByName("SC2")
 ElseIf file = 4 Then
  Set n = d4.GetNodeByName("SC2")
 End If
  'Enter the evidence to SC2
 n.SelectState (Index)
 EHOLD(2, 4) = Index
End Sub

Private Sub Scopecw3_Click(Index As Integer)

  'Get node name with name of SCOPE of work3 at current time
 If file = 1 Then
  Set n = d1.GetNodeByName("SC3")
 ElseIf file = 2 Then
  Set n = d2.GetNodeByName("SC3")
 ElseIf file = 3 Then
  Set n = d3.GetNodeByName("SC3")
 ElseIf file = 4 Then
  Set n = d4.GetNodeByName("SC3")
 End If
  'Enter the evidence to SC3
 n.SelectState (Index)
 EHOLD(3, 4) = Index
End Sub

Private Sub SPIcw1_Click(Index As Integer)

  'Get node name with name of SPI of work1 at current time
 If file = 1 Then
  Set n = d1.GetNodeByName("SPIC1")
 ElseIf file = 2 Then
  Set n = d2.GetNodeByName("SPIC1")
 ElseIf file = 3 Then
```

```
  Set n = d3.GetNodeByName("SPIC1")
 ElseIf file = 4 Then
  Set n = d4.GetNodeByName("SPIC1")
 End If
 'Enter the evidence to SPIC1
 n.SelectState (Index)
 EHOLD(1, 8) = Index
End Sub

Private Sub SPIcw2_Click(Index As Integer)

 'Get node name with name of SPI of work2 at current time
 If file = 1 Then
  Set n = d1.GetNodeByName("SPIC2")
 ElseIf file = 2 Then
  Set n = d2.GetNodeByName("SPIC2")
 ElseIf file = 3 Then
  Set n = d3.GetNodeByName("SPIC2")
 ElseIf file = 4 Then
  Set n = d4.GetNodeByName("SPIC2")
 End If
 'Enter the evidence to SPIC2
 n.SelectState (Index)
 EHOLD(2, 8) = Index
End Sub

Private Sub SPIcw3_Click(Index As Integer)

 'Get node name with name of SPI of work3 at current time
 If file = 1 Then
  Set n = d1.GetNodeByName("SPIC3")
 ElseIf file = 2 Then
  Set n = d2.GetNodeByName("SPIC3")
 ElseIf file = 3 Then
  Set n = d3.GetNodeByName("SPIC3")
 ElseIf file = 4 Then
  Set n = d4.GetNodeByName("SPIC3")
 End If
 'Enter the evidence to SPIC3
 n.SelectState (Index)
  EHOLD(3, 8) = Index
End Sub

Private Sub Timecw1_Click(Index As Integer)

 'Get node name with name of Time of work1 at current time
 If file = 1 Then
  Set n = d1.GetNodeByName("TC1")
 ElseIf file = 2 Then
  Set n = d2.GetNodeByName("TC1")
 ElseIf file = 3 Then
  Set n = d3.GetNodeByName("TC1")
 ElseIf file = 4 Then
  Set n = d4.GetNodeByName("TC1")
 End If
 'Enter the evidence to TC1
 n.SelectState (Index)
 EHOLD(1, 1) = Index

End Sub

Private Sub Timecw2_Click(Index As Integer)

 'Get node name with name of Time of work2 at current time
 If file = 1 Then
  Set n = d1.GetNodeByName("TC2")
 ElseIf file = 2 Then
  Set n = d2.GetNodeByName("TC2")
 ElseIf file = 3 Then
  Set n = d3.GetNodeByName("TC2")
```

```
 ElseIf file = 4 Then
  Set n = d4.GetNodeByName("TC2")
 End If
  'Enter the evidence to TC2
  n.SelectState (Index)
  EHOLD(2, 1) = Index
End Sub

Private Sub Timecw3_Click(Index As Integer)

  'Get node name with name of Time of work3 at current time
 If file = 1 Then
  Set n = d1.GetNodeByName("TC3")
 ElseIf file = 2 Then
  Set n = d2.GetNodeByName("TC3")
 ElseIf file = 3 Then
  Set n = d3.GetNodeByName("TC3")
 ElseIf file = 4 Then
  Set n = d4.GetNodeByName("TC3")
 End If
  'Enter the evidence to TC3
  n.SelectState (Index)
   EHOLD(3, 1) = Index
End Sub

Private Sub Unseenbutton()

  'Delete the option controls
 timew1.Visible = False
 costw1.Visible = False
 qualityw1.Visible = False
 scopew1.Visible = False
 clientw1.Visible = False
 humanw1.Visible = False
 materialw1.Visible = False
 spiw1.Visible = False
 cpiw1.Visible = False

 timew2.Visible = False
 costw2.Visible = False
 qualityw2.Visible = False
 scopew2.Visible = False
 clientw2.Visible = False
 humanw2.Visible = False
 materialw2.Visible = False
 spiw2.Visible = False
 cpiw2.Visible = False

 timew3.Visible = False
 costw3.Visible = False
 qualityw3.Visible = False
 scopew3.Visible = False
 clientw3.Visible = False
 humanw3.Visible = False
 materialw3.Visible = False
 spiw3.Visible = False
 cpiw3.Visible = False

End Sub

Private Sub Update_Click()

 Dim A(1 To 3), B(1 To 3), C(1 To 3) As Integer
 Dim i, Evidence As Integer

  For i = 0 To 2
   If Timecw1(i).Value = False And Costcw1(i).Value = False And Qualitycw1(i).Value = False And Scopecw1(i).Value = False And
       Clientcw1(i).Value = False And Humancw1(i).Value = False And Materialcw1(i).Value = False And CPIcw1(i).Value = False
       And SPIcw1(i).Value = False Then
    A(i + 1) = 0
```

```
Else
  A(i + 1) = 1
End If

If Timecw2(i).Value = False And Costcw2(i).Value = False And Qualitycw2(i).Value = False And Scopecw2(i).Value = False And
  Clientcw2(i).Value = False And Humancw2(i).Value = False And Materialcw2(i).Value = False And CPIcw2(i).Value = False
  And SPIcw2(i).Value = False Then
 B(i + 1) = 0
Else
 B(i + 1) = 1
End If

If Timecw3(i).Value = False And Costcw3(i).Value = False And Qualitycw3(i).Value = False And Scopecw3(i).Value = False And
  Clientcw3(i).Value = False And Humancw3(i).Value = False And Materialcw3(i).Value = False And CPIcw3(i).Value = False
  And SPIcw3(i).Value = False Then
 C(i + 1) = 0
Else
 C(i + 1) = 1
End If

Next i

Evidence = A(1) + A(2) + A(3) + B(1) + B(2) + B(3) + C(1) + C(2) + C(3)

If Evidence = 0 Then   ' Corresponding EDNIF locates the end of this subroutine
 MsgBox "PLEASE ENTER THE EVIDENCE!!", , "NO EVIDENCE"
Else

  Call Clearbar
  PriorPost = 1

 If file = 1 Then
   Call d1.Propagate(HAPI.hEquilibriumSum, HAPI.hModeNormal)
   Call showresult(file, 1)

 ElseIf file = 2 Then
   Call d2.Propagate(HAPI.hEquilibriumSum, HAPI.hModeNormal)
   Call showresult(file, 1)

 ElseIf file = 3 Then
   Call d3.Propagate(HAPI.hEquilibriumSum, HAPI.hModeNormal)
   Call showresult(file, 1)

 ElseIf file = 4 Then
   Call d4.Propagate(HAPI.hEquilibriumSum, HAPI.hModeNormal)
   Call showresult(file, 1)
 End If

End If  ' corresponding to the Msgbox if

End Sub

Private Sub showresult(file, color)

Dim i, j, Wfile, Barcolor As Integer
Dim Tevi(1 To 3, 1 To 12, 1 To 3), Cevi(1 To 3, 1 To 12, 1 To 3), Qevi(1 To 3, 1 To 12, 1 To 3), Sevi(1 To 3, 1 To 12, 1 To 3) As
    Single
Dim Clevi(1 To 3, 1 To 12, 1 To 3), Hevi(1 To 3, 1 To 12, 1 To 3), Mevi(1 To 3, 1 To 12, 1 To 3) As Single
    ' Tevi(Group, Timestep, states) - Time evidence
Dim TEMPSPIO(1 To 12, 1 To 3), TEMPCPIO(1 To 12, 1 To 3) As Single
Dim SPIO(1 To 3, 1 To 3), CPIO(1 To 3, 1 To 3) As Single
    'SPI overall (Timestep, states)

  Wfile = file

  If color = 0 Then
   Barcolor = 10   '10 means green
  ElseIf color = 1 Then
   Barcolor = 12    ' 12 is red
  End If
```

```
If Wfile = 1 Then

'-------------------------------------------------------------------------------------
' find 1,2 and 3rd time step SPI and CPI for overall project
'-------------------------------------------------------------------------------------

    Set n = d1.GetNodeByName("SPI1O")
     TEMPSPIO(1, 1) = n.Belief(0)
     TEMPSPIO(1, 2) = n.Belief(1)
     TEMPSPIO(1, 3) = n.Belief(2)

    Set n = d1.GetNodeByName("CPI1O")
     TEMPCPIO(1, 1) = n.Belief(0)
     TEMPCPIO(1, 2) = n.Belief(1)
     TEMPCPIO(1, 3) = n.Belief(2)

    For i = 2 To 12  'Tm3

      'Read the evidence for group 2
      Set n = d1.GetNodeByName("T12")
        Tevi(2, i, 1) = n.Belief(0)
        Tevi(2, i, 2) = n.Belief(1)
        Tevi(2, i, 3) = n.Belief(2)
      Set n = d1.GetNodeByName("C12")
        Cevi(2, i, 1) = n.Belief(0)
        Cevi(2, i, 2) = n.Belief(1)
        Cevi(2, i, 3) = n.Belief(2)
      Set n = d1.GetNodeByName("S12")
        Sevi(2, i, 1) = n.Belief(0)
        Sevi(2, i, 2) = n.Belief(1)
        Sevi(2, i, 3) = n.Belief(2)

      'Read the evidence for group 3
      Set n = d1.GetNodeByName("T13")
        Tevi(3, i, 1) = n.Belief(0)
        Tevi(3, i, 2) = n.Belief(1)
        Tevi(3, i, 3) = n.Belief(2)
      Set n = d1.GetNodeByName("C13")
        Cevi(3, i, 1) = n.Belief(0)
        Cevi(3, i, 2) = n.Belief(1)
        Cevi(3, i, 3) = n.Belief(2)
      Set n = d1.GetNodeByName("S13")
        Sevi(3, i, 1) = n.Belief(0)
        Sevi(3, i, 2) = n.Belief(1)
        Sevi(3, i, 3) = n.Belief(2)

       If PriorPost = 1 Then
         d1.Initialize
       End If

      'ENter the evidence for group2
      Set n = d1.GetNodeByName("TC2")
       n.Finding(0) = Tevi(2, i, 1)
       n.Finding(1) = Tevi(2, i, 2)
       n.Finding(2) = Tevi(2, i, 3)
      Set n = d1.GetNodeByName("CC2")
       n.Finding(0) = Cevi(2, i, 1)
       n.Finding(1) = Cevi(2, i, 2)
       n.Finding(2) = Cevi(2, i, 3)
      Set n = d1.GetNodeByName("SC2")
       n.Finding(0) = Sevi(2, i, 1)
       n.Finding(1) = Sevi(2, i, 2)
       n.Finding(2) = Sevi(2, i, 3)

      'ENter the evidence for group3
      Set n = d1.GetNodeByName("TC3")
       n.Finding(0) = Tevi(3, i, 1)
       n.Finding(1) = Tevi(3, i, 2)
       n.Finding(2) = Tevi(3, i, 3)
```

```
      Set n = d1.GetNodeByName("CC3")
       n.Finding(0) = Cevi(3, i, 1)
       n.Finding(1) = Cevi(3, i, 2)
       n.Finding(2) = Cevi(3, i, 3)
      Set n = d1.GetNodeByName("SC3")
       n.Finding(0) = Sevi(3, i, 1)
       n.Finding(1) = Sevi(3, i, 2)
       n.Finding(2) = Sevi(3, i, 3)

     Call d1.Propagate(HAPI.hEquilibriumSum, HAPI.hModeNormal)

      Set n = d1.GetNodeByName("SPI1O")
        TEMPSPIO(i, 1) = n.Belief(0)
        TEMPSPIO(i, 2) = n.Belief(1)
        TEMPSPIO(i, 3) = n.Belief(2)
     Set n = d1.GetNodeByName("CPI1O")
        TEMPCPIO(i, 1) = n.Belief(0)
        TEMPCPIO(i, 2) = n.Belief(1)
        TEMPCPIO(i, 3) = n.Belief(2)

   Next i

ElseIf Wfile = 2 Then

'-----------------------------------------------------------------------------------------------
' find 1,2 and 3rd time step SPI and CPI for overall project
'------------------------------------------------------------------------------------------------

    Set n = d2.GetNodeByName("SPI1O")
     TEMPSPIO(1, 1) = n.Belief(0)
     TEMPSPIO(1, 2) = n.Belief(1)
     TEMPSPIO(1, 3) = n.Belief(2)

    Set n = d2.GetNodeByName("CPI1O")
     TEMPCPIO(1, 1) = n.Belief(0)
     TEMPCPIO(1, 2) = n.Belief(1)
     TEMPCPIO(1, 3) = n.Belief(2)

   For i = 2 To 12 ' Tm3
      'Read the evidence for group 2
      Set n = d2.GetNodeByName("T12")
       Tevi(2, i, 1) = n.Belief(0)
       Tevi(2, i, 2) = n.Belief(1)
       Tevi(2, i, 3) = n.Belief(2)
      Set n = d2.GetNodeByName("C12")
       Cevi(2, i, 1) = n.Belief(0)
       Cevi(2, i, 2) = n.Belief(1)
       Cevi(2, i, 3) = n.Belief(2)
      Set n = d2.GetNodeByName("S12")
       Sevi(2, i, 1) = n.Belief(0)
       Sevi(2, i, 2) = n.Belief(1)
       Sevi(2, i, 3) = n.Belief(2)
      Set n = d2.GetNodeByName("CL12")
       Clevi(2, i, 1) = n.Belief(0)
       Clevi(2, i, 2) = n.Belief(1)
       Clevi(2, i, 3) = n.Belief(2)

      'Read the evidence for group 3
      Set n = d2.GetNodeByName("T13")
       Tevi(3, i, 1) = n.Belief(0)
       Tevi(3, i, 2) = n.Belief(1)
       Tevi(3, i, 3) = n.Belief(2)
      Set n = d2.GetNodeByName("C13")
       Cevi(3, i, 1) = n.Belief(0)
       Cevi(3, i, 2) = n.Belief(1)
       Cevi(3, i, 3) = n.Belief(2)
      Set n = d2.GetNodeByName("S13")
       Sevi(3, i, 1) = n.Belief(0)
       Sevi(3, i, 2) = n.Belief(1)
       Sevi(3, i, 3) = n.Belief(2)
```

```
        Set n = d2.GetNodeByName("CL13")
          Clevi(3, i, 1) = n.Belief(0)
          Clevi(3, i, 2) = n.Belief(1)
          Clevi(3, i, 3) = n.Belief(2)

         If PriorPost = 1 Then
           d2.Initialize
         End If

       'ENter the evidence for group2
        Set n = d2.GetNodeByName("TC2")
         n.Finding(0) = Tevi(2, i, 1)
         n.Finding(1) = Tevi(2, i, 2)
         n.Finding(2) = Tevi(2, i, 3)
        Set n = d2.GetNodeByName("CC2")
         n.Finding(0) = Cevi(2, i, 1)
         n.Finding(1) = Cevi(2, i, 2)
         n.Finding(2) = Cevi(2, i, 3)
        Set n = d2.GetNodeByName("SC2")
         n.Finding(0) = Sevi(2, i, 1)
         n.Finding(1) = Sevi(2, i, 2)
         n.Finding(2) = Sevi(2, i, 3)
        Set n = d2.GetNodeByName("CLC2")
         n.Finding(0) = Clevi(2, i, 1)
         n.Finding(1) = Clevi(2, i, 2)
         n.Finding(2) = Clevi(2, i, 3)

       'ENter the evidence for group3
        Set n = d2.GetNodeByName("TC3")
         n.Finding(0) = Tevi(3, i, 1)
         n.Finding(1) = Tevi(3, i, 2)
         n.Finding(2) = Tevi(3, i, 3)
        Set n = d2.GetNodeByName("CC3")
         n.Finding(0) = Cevi(3, i, 1)
         n.Finding(1) = Cevi(3, i, 2)
         n.Finding(2) = Cevi(3, i, 3)
        Set n = d2.GetNodeByName("SC3")
         n.Finding(0) = Sevi(3, i, 1)
         n.Finding(1) = Sevi(3, i, 2)
         n.Finding(2) = Sevi(3, i, 3)
        Set n = d2.GetNodeByName("CLC3")
         n.Finding(0) = Clevi(3, i, 1)
         n.Finding(1) = Clevi(3, i, 2)
         n.Finding(2) = Clevi(3, i, 3)

      Call d2.Propagate(HAPI.hEquilibriumSum, HAPI.hModeNormal)

        Set n = d2.GetNodeByName("SPI1O")
          TEMPSPIO(i, 1) = n.Belief(0)
          TEMPSPIO(i, 2) = n.Belief(1)
          TEMPSPIO(i, 3) = n.Belief(2)
       Set n = d2.GetNodeByName("CPI1O")
          TEMPCPIO(i, 1) = n.Belief(0)
          TEMPCPIO(i, 2) = n.Belief(1)
          TEMPCPIO(i, 3) = n.Belief(2)

    Next i

ElseIf Wfile = 3 Then

'--------------------------------------------------------------------------------
' find 1,2 and 3rd time step SPI and CPI for overall project
'--------------------------------------------------------------------------------

     Set n = d3.GetNodeByName("SPI1O")
      TEMPSPIO(1, 1) = n.Belief(0)
      TEMPSPIO(1, 2) = n.Belief(1)
      TEMPSPIO(1, 3) = n.Belief(2)

     Set n = d3.GetNodeByName("CPI1O")
```

```
 TEMPCPIO(1, 1) = n.Belief(0)
 TEMPCPIO(1, 2) = n.Belief(1)
 TEMPCPIO(1, 3) = n.Belief(2)

For i = 2 To 12 ' Tm3
   'Read the evidence for group 2
   Set n = d3.GetNodeByName("T12")
    Tevi(2, i, 1) = n.Belief(0)
    Tevi(2, i, 2) = n.Belief(1)
    Tevi(2, i, 3) = n.Belief(2)
   Set n = d3.GetNodeByName("C12")
    Cevi(2, i, 1) = n.Belief(0)
    Cevi(2, i, 2) = n.Belief(1)
    Cevi(2, i, 3) = n.Belief(2)
   Set n = d3.GetNodeByName("S12")
    Sevi(2, i, 1) = n.Belief(0)
    Sevi(2, i, 2) = n.Belief(1)
    Sevi(2, i, 3) = n.Belief(2)
   Set n = d3.GetNodeByName("CL12")
    Clevi(2, i, 1) = n.Belief(0)
    Clevi(2, i, 2) = n.Belief(1)
    Clevi(2, i, 3) = n.Belief(2)
   Set n = d3.GetNodeByName("Q12")
    Qevi(2, i, 1) = n.Belief(0)
    Qevi(2, i, 2) = n.Belief(1)
    Qevi(2, i, 3) = n.Belief(2)

   'Read the evidence for group 3
   Set n = d3.GetNodeByName("T13")
    Tevi(3, i, 1) = n.Belief(0)
    Tevi(3, i, 2) = n.Belief(1)
    Tevi(3, i, 3) = n.Belief(2)
   Set n = d3.GetNodeByName("C13")
    Cevi(3, i, 1) = n.Belief(0)
    Cevi(3, i, 2) = n.Belief(1)
    Cevi(3, i, 3) = n.Belief(2)
   Set n = d3.GetNodeByName("S13")
    Sevi(3, i, 1) = n.Belief(0)
    Sevi(3, i, 2) = n.Belief(1)
    Sevi(3, i, 3) = n.Belief(2)
   Set n = d3.GetNodeByName("CL13")
    Clevi(3, i, 1) = n.Belief(0)
    Clevi(3, i, 2) = n.Belief(1)
    Clevi(3, i, 3) = n.Belief(2)
   Set n = d3.GetNodeByName("Q13")
    Qevi(3, i, 1) = n.Belief(0)
    Qevi(3, i, 2) = n.Belief(1)
    Qevi(3, i, 3) = n.Belief(2)

    If PriorPost = 1 Then
     d3.Initialize
    End If

   'ENter the evidence for group2
   Set n = d3.GetNodeByName("TC2")
    n.Finding(0) = Tevi(2, i, 1)
    n.Finding(1) = Tevi(2, i, 2)
    n.Finding(2) = Tevi(2, i, 3)
   Set n = d3.GetNodeByName("CC2")
    n.Finding(0) = Cevi(2, i, 1)
    n.Finding(1) = Cevi(2, i, 2)
    n.Finding(2) = Cevi(2, i, 3)
   Set n = d3.GetNodeByName("SC2")
    n.Finding(0) = Sevi(2, i, 1)
    n.Finding(1) = Sevi(2, i, 2)
    n.Finding(2) = Sevi(2, i, 3)
   Set n = d3.GetNodeByName("CLC2")
    n.Finding(0) = Clevi(2, i, 1)
    n.Finding(1) = Clevi(2, i, 2)
    n.Finding(2) = Clevi(2, i, 3)
```

```
        Set n = d3.GetNodeByName("QC2")
         n.Finding(0) = Qevi(2, i, 1)
         n.Finding(1) = Qevi(2, i, 2)
         n.Finding(2) = Qevi(2, i, 3)

        'ENter the evidence for group3
        Set n = d3.GetNodeByName("TC3")
         n.Finding(0) = Tevi(3, i, 1)
         n.Finding(1) = Tevi(3, i, 2)
         n.Finding(2) = Tevi(3, i, 3)
        Set n = d3.GetNodeByName("CC3")
         n.Finding(0) = Cevi(3, i, 1)
         n.Finding(1) = Cevi(3, i, 2)
         n.Finding(2) = Cevi(3, i, 3)
        Set n = d3.GetNodeByName("SC3")
         n.Finding(0) = Sevi(3, i, 1)
         n.Finding(1) = Sevi(3, i, 2)
         n.Finding(2) = Sevi(3, i, 3)
        Set n = d3.GetNodeByName("CLC3")
         n.Finding(0) = Clevi(3, i, 1)
         n.Finding(1) = Clevi(3, i, 2)
         n.Finding(2) = Clevi(3, i, 3)
        Set n = d3.GetNodeByName("QC3")
         n.Finding(0) = Qevi(3, i, 1)
         n.Finding(1) = Qevi(3, i, 2)
         n.Finding(2) = Qevi(3, i, 3)

      Call d3.Propagate(HAPI.hEquilibriumSum, HAPI.hModeNormal)

       Set n = d3.GetNodeByName("SPI1O")
         TEMPSPIO(i, 1) = n.Belief(0)
         TEMPSPIO(i, 2) = n.Belief(1)
         TEMPSPIO(i, 3) = n.Belief(2)
       Set n = d3.GetNodeByName("CPI1O")
         TEMPCPIO(i, 1) = n.Belief(0)
         TEMPCPIO(i, 2) = n.Belief(1)
         TEMPCPIO(i, 3) = n.Belief(2)

    Next i

ElseIf Wfile = 4 Then

'-------------------------------------------------------------------------------
' find 1,2 and 3rd time step SPI and CPI for overall project
'-------------------------------------------------------------------------------

     Set n = d4.GetNodeByName("SPI1O")
      TEMPSPIO(1, 1) = n.Belief(0)
      TEMPSPIO(1, 2) = n.Belief(1)
      TEMPSPIO(1, 3) = n.Belief(2)

     Set n = d4.GetNodeByName("CPI1O")
      TEMPCPIO(1, 1) = n.Belief(0)
      TEMPCPIO(1, 2) = n.Belief(1)
      TEMPCPIO(1, 3) = n.Belief(2)

    For i = 2 To 12 'Tm3
          'Read the evidence for group 1
       Set n = d4.GetNodeByName("T11")
        Tevi(1, i, 1) = n.Belief(0)
        Tevi(1, i, 2) = n.Belief(1)
        Tevi(1, i, 3) = n.Belief(2)
       Set n = d4.GetNodeByName("C11")
        Cevi(1, i, 1) = n.Belief(0)
        Cevi(1, i, 2) = n.Belief(1)
        Cevi(1, i, 3) = n.Belief(2)
       Set n = d4.GetNodeByName("S11")
        Sevi(1, i, 1) = n.Belief(0)
        Sevi(1, i, 2) = n.Belief(1)
        Sevi(1, i, 3) = n.Belief(2)
```

```
Set n = d4.GetNodeByName("CL11")
 Clevi(1, i, 1) = n.Belief(0)
 Clevi(1, i, 2) = n.Belief(1)
 Clevi(1, i, 3) = n.Belief(2)
Set n = d4.GetNodeByName("Q11")
 Qevi(1, i, 1) = n.Belief(0)
 Qevi(1, i, 2) = n.Belief(1)
 Qevi(1, i, 3) = n.Belief(2)
Set n = d4.GetNodeByName("H11")
 Hevi(1, i, 1) = n.Belief(0)
 Hevi(1, i, 2) = n.Belief(1)
 Hevi(1, i, 3) = n.Belief(2)
Set n = d4.GetNodeByName("M11")
 Mevi(1, i, 1) = n.Belief(0)
 Mevi(1, i, 2) = n.Belief(1)
 Mevi(1, i, 3) = n.Belief(2)

'Read the evidence for group 2
Set n = d4.GetNodeByName("T12")
 Tevi(2, i, 1) = n.Belief(0)
 Tevi(2, i, 2) = n.Belief(1)
 Tevi(2, i, 3) = n.Belief(2)
Set n = d4.GetNodeByName("C12")
 Cevi(2, i, 1) = n.Belief(0)
 Cevi(2, i, 2) = n.Belief(1)
 Cevi(2, i, 3) = n.Belief(2)
Set n = d4.GetNodeByName("S12")
 Sevi(2, i, 1) = n.Belief(0)
 Sevi(2, i, 2) = n.Belief(1)
 Sevi(2, i, 3) = n.Belief(2)
Set n = d4.GetNodeByName("CL12")
 Clevi(2, i, 1) = n.Belief(0)
 Clevi(2, i, 2) = n.Belief(1)
 Clevi(2, i, 3) = n.Belief(2)
Set n = d4.GetNodeByName("Q12")
 Qevi(2, i, 1) = n.Belief(0)
 Qevi(2, i, 2) = n.Belief(1)
 Qevi(2, i, 3) = n.Belief(2)
Set n = d4.GetNodeByName("H12")
 Hevi(2, i, 1) = n.Belief(0)
 Hevi(2, i, 2) = n.Belief(1)
 Hevi(2, i, 3) = n.Belief(2)
Set n = d4.GetNodeByName("M12")
 Mevi(2, i, 1) = n.Belief(0)
 Mevi(2, i, 2) = n.Belief(1)
 Mevi(2, i, 3) = n.Belief(2)

'Read the evidence for group 3
Set n = d4.GetNodeByName("T13")
 Tevi(3, i, 1) = n.Belief(0)
 Tevi(3, i, 2) = n.Belief(1)
 Tevi(3, i, 3) = n.Belief(2)
Set n = d4.GetNodeByName("C13")
 Cevi(3, i, 1) = n.Belief(0)
 Cevi(3, i, 2) = n.Belief(1)
 Cevi(3, i, 3) = n.Belief(2)
Set n = d4.GetNodeByName("S13")
 Sevi(3, i, 1) = n.Belief(0)
 Sevi(3, i, 2) = n.Belief(1)
 Sevi(3, i, 3) = n.Belief(2)
Set n = d4.GetNodeByName("CL13")
 Clevi(3, i, 1) = n.Belief(0)
 Clevi(3, i, 2) = n.Belief(1)
 Clevi(3, i, 3) = n.Belief(2)
Set n = d4.GetNodeByName("Q13")
 Qevi(3, i, 1) = n.Belief(0)
 Qevi(3, i, 2) = n.Belief(1)
 Qevi(3, i, 3) = n.Belief(2)
Set n = d4.GetNodeByName("H13")
 Hevi(3, i, 1) = n.Belief(0)
```

```
 Hevi(3, i, 2) = n.Belief(1)
 Hevi(3, i, 3) = n.Belief(2)
Set n = d4.GetNodeByName("M13")
 Mevi(3, i, 1) = n.Belief(0)
 Mevi(3, i, 2) = n.Belief(1)
 Mevi(3, i, 3) = n.Belief(2)

If PriorPost = 1 Then
  d4.Initialize
End If

'ENter the evidence for group1
Set n = d4.GetNodeByName("TC1")
 n.Finding(0) = Tevi(1, i, 1)
 n.Finding(1) = Tevi(1, i, 2)
 n.Finding(2) = Tevi(1, i, 3)
Set n = d4.GetNodeByName("CC1")
 n.Finding(0) = Cevi(1, i, 1)
 n.Finding(1) = Cevi(1, i, 2)
 n.Finding(2) = Cevi(1, i, 3)
Set n = d4.GetNodeByName("SC1")
 n.Finding(0) = Sevi(1, i, 1)
 n.Finding(1) = Sevi(1, i, 2)
 n.Finding(2) = Sevi(1, i, 3)
Set n = d4.GetNodeByName("CLC1")
 n.Finding(0) = Clevi(1, i, 1)
 n.Finding(1) = Clevi(1, i, 2)
 n.Finding(2) = Clevi(1, i, 3)
Set n = d4.GetNodeByName("QC1")
 n.Finding(0) = Qevi(1, i, 1)
 n.Finding(1) = Qevi(1, i, 2)
 n.Finding(2) = Qevi(1, i, 3)
Set n = d4.GetNodeByName("HC1")
 n.Finding(0) = Hevi(1, i, 1)
 n.Finding(1) = Hevi(1, i, 2)
 n.Finding(2) = Hevi(1, i, 3)
Set n = d4.GetNodeByName("MC1")
 n.Finding(0) = Mevi(1, i, 1)
 n.Finding(1) = Mevi(1, i, 2)
 n.Finding(2) = Mevi(1, i, 3)

'ENter the evidence for group2
Set n = d4.GetNodeByName("TC2")
 n.Finding(0) = Tevi(2, i, 1)
 n.Finding(1) = Tevi(2, i, 2)
 n.Finding(2) = Tevi(2, i, 3)
Set n = d4.GetNodeByName("CC2")
 n.Finding(0) = Cevi(2, i, 1)
 n.Finding(1) = Cevi(2, i, 2)
 n.Finding(2) = Cevi(2, i, 3)
Set n = d4.GetNodeByName("SC2")
 n.Finding(0) = Sevi(2, i, 1)
 n.Finding(1) = Sevi(2, i, 2)
 n.Finding(2) = Sevi(2, i, 3)
Set n = d4.GetNodeByName("CLC2")
 n.Finding(0) = Clevi(2, i, 1)
 n.Finding(1) = Clevi(2, i, 2)
 n.Finding(2) = Clevi(2, i, 3)
Set n = d4.GetNodeByName("QC2")
 n.Finding(0) = Qevi(2, i, 1)
 n.Finding(1) = Qevi(2, i, 2)
 n.Finding(2) = Qevi(2, i, 3)
Set n = d4.GetNodeByName("HC2")
 n.Finding(0) = Hevi(2, i, 1)
 n.Finding(1) = Hevi(2, i, 2)
 n.Finding(2) = Hevi(2, i, 3)
Set n = d4.GetNodeByName("MC2")
 n.Finding(0) = Mevi(2, i, 1)
 n.Finding(1) = Mevi(2, i, 2)
 n.Finding(2) = Mevi(2, i, 3)
```

```
'ENter the evidence for group3
 Set n = d4.GetNodeByName("TC3")
  n.Finding(0) = Tevi(3, i, 1)
  n.Finding(1) = Tevi(3, i, 2)
  n.Finding(2) = Tevi(3, i, 3)
 Set n = d4.GetNodeByName("CC3")
  n.Finding(0) = Cevi(3, i, 1)
  n.Finding(1) = Cevi(3, i, 2)
  n.Finding(2) = Cevi(3, i, 3)
 Set n = d4.GetNodeByName("SC3")
  n.Finding(0) = Sevi(3, i, 1)
  n.Finding(1) = Sevi(3, i, 2)
  n.Finding(2) = Sevi(3, i, 3)
 Set n = d4.GetNodeByName("CLC3")
  n.Finding(0) = Clevi(3, i, 1)
  n.Finding(1) = Clevi(3, i, 2)
  n.Finding(2) = Clevi(3, i, 3)
 Set n = d4.GetNodeByName("QC3")
  n.Finding(0) = Qevi(3, i, 1)
  n.Finding(1) = Qevi(3, i, 2)
  n.Finding(2) = Qevi(3, i, 3)
 Set n = d4.GetNodeByName("HC3")
  n.Finding(0) = Hevi(3, i, 1)
  n.Finding(1) = Hevi(3, i, 2)
  n.Finding(2) = Hevi(3, i, 3)
 Set n = d4.GetNodeByName("MC3")
  n.Finding(0) = Mevi(3, i, 1)
  n.Finding(1) = Mevi(3, i, 2)
  n.Finding(2) = Mevi(3, i, 3)

Call d4.Propagate(HAPI.hEquilibriumSum, HAPI.hModeNormal)

 Set n = d4.GetNodeByName("SPI1O")
  TEMPSPIO(i, 1) = n.Belief(0)
  TEMPSPIO(i, 2) = n.Belief(1)
  TEMPSPIO(i, 3) = n.Belief(2)
 Set n = d4.GetNodeByName("CPI1O")
  TEMPCPIO(i, 1) = n.Belief(0)
  TEMPCPIO(i, 2) = n.Belief(1)
  TEMPCPIO(i, 3) = n.Belief(2)

Next i

End If

' FIND 3 FUTURE TIME STEPS SPI AND CPI
 SPIO(1, 1) = TEMPSPIO(Tm1, 1)
 SPIO(1, 2) = TEMPSPIO(Tm1, 2)
 SPIO(1, 3) = TEMPSPIO(Tm1, 3)
 CPIO(1, 1) = TEMPCPIO(Tm1, 1)
 CPIO(1, 2) = TEMPCPIO(Tm1, 2)
 CPIO(1, 3) = TEMPCPIO(Tm1, 3)

 SPIO(2, 1) = TEMPSPIO(Tm2, 1)
 SPIO(2, 2) = TEMPSPIO(Tm2, 2)
 SPIO(2, 3) = TEMPSPIO(Tm2, 3)
 CPIO(2, 1) = TEMPCPIO(Tm2, 1)
 CPIO(2, 2) = TEMPCPIO(Tm2, 2)
 CPIO(2, 3) = TEMPCPIO(Tm2, 3)

 SPIO(3, 1) = TEMPSPIO(Tm3, 1)
 SPIO(3, 2) = TEMPSPIO(Tm3, 2)
 SPIO(3, 3) = TEMPSPIO(Tm3, 3)
 CPIO(3, 1) = TEMPCPIO(Tm3, 1)
 CPIO(3, 2) = TEMPCPIO(Tm3, 2)
 CPIO(3, 3) = TEMPCPIO(Tm3, 3)


If file = 1 Then
```

```
  d1.Initialize
ElseIf file = 2 Then
  d2.Initialize
ElseIf file = 3 Then
  d3.Initialize
ElseIf file = 4 Then
  d4.Initialize
End If

Call Evidencehold

 '+++++++++++++++++++++++++++++
 ' DISPLAY THE RESULTS
 '+++++++++++++++++++++++++++++

 ' FOR 1ST TIME STEP

 SPI1O0.Caption = Format(SPIO(1, 1) * 100, "##0.000") & "%"
 SPI1O1.Caption = Format(SPIO(1, 2) * 100, "##0.000") & "%"
 SPI1O2.Caption = Format(SPIO(1, 3) * 100, "##0.000") & "%"
 SPI1A.ForeColor = QBColor(Barcolor)     ' &HFF00& IS GREEEN COLOR CODE
 SPI1B.ForeColor = QBColor(Barcolor)
 SPI1C.ForeColor = QBColor(Barcolor)
 SPI1A.Line (0, 0)-(Int(1200 * SPIO(1, 1)), 180), , BF
 SPI1B.Line (0, 0)-(Int(1200 * SPIO(1, 2)), 180), , BF
 SPI1C.Line (0, 0)-(Int(1200 * SPIO(1, 3)), 180), , BF

 ' Get 1-month future overall CPI and display
 CPI1O0.Caption = Format(CPIO(1, 1) * 100, "##0.000") & "%"
 CPI1O1.Caption = Format(CPIO(1, 2) * 100, "##0.000") & "%"
 CPI1O2.Caption = Format(CPIO(1, 3) * 100, "##0.000") & "%"
 CPI1A.ForeColor = QBColor(Barcolor)
 CPI1B.ForeColor = QBColor(Barcolor)
 CPI1C.ForeColor = QBColor(Barcolor)
 CPI1A.Line (0, 0)-(Int(1200 * CPIO(1, 1)), 180), , BF
 CPI1B.Line (0, 0)-(Int(1200 * CPIO(1, 2)), 180), , BF
 CPI1C.Line (0, 0)-(Int(1200 * CPIO(1, 3)), 180), , BF

' FOR 2ND TIME STEP
 SPI2O0.Caption = Format(SPIO(2, 1) * 100, "##0.000") & "%"
 SPI2O1.Caption = Format(SPIO(2, 2) * 100, "##0.000") & "%"
 SPI2O2.Caption = Format(SPIO(2, 3) * 100, "##0.000") & "%"
 SPI2A.ForeColor = QBColor(Barcolor)     ' QBColor(Barcolor) IS GREEEN COLOR CODE
 SPI2B.ForeColor = QBColor(Barcolor)
 SPI2C.ForeColor = QBColor(Barcolor)
 SPI2A.Line (0, 0)-(Int(1200 * SPIO(2, 1)), 180), , BF
 SPI2B.Line (0, 0)-(Int(1200 * SPIO(2, 2)), 180), , BF
 SPI2C.Line (0, 0)-(Int(1200 * SPIO(2, 3)), 180), , BF

 CPI2O0.Caption = Format(CPIO(2, 1) * 100, "##0.000") & "%"
 CPI2O1.Caption = Format(CPIO(2, 2) * 100, "##0.000") & "%"
 CPI2O2.Caption = Format(CPIO(2, 3) * 100, "##0.000") & "%"
 CPI2A.ForeColor = QBColor(Barcolor)
 CPI2B.ForeColor = QBColor(Barcolor)
 CPI2C.ForeColor = QBColor(Barcolor)
 CPI2A.Line (0, 0)-(Int(1200 * CPIO(2, 1)), 180), , BF
 CPI2B.Line (0, 0)-(Int(1200 * CPIO(2, 2)), 180), , BF
 CPI2C.Line (0, 0)-(Int(1200 * CPIO(2, 3)), 180), , BF

'' FOR 3RD TIME STEP
 SPI3O0.Caption = Format(SPIO(3, 1) * 100, "##0.000") & "%"
 SPI3O1.Caption = Format(SPIO(3, 2) * 100, "##0.000") & "%"
 SPI3O2.Caption = Format(SPIO(3, 3) * 100, "##0.000") & "%"
 SPI3A.ForeColor = QBColor(Barcolor)     ' &HFF00& IS GREEEN COLOR CODE
 SPI3B.ForeColor = QBColor(Barcolor)
 SPI3C.ForeColor = QBColor(Barcolor)
 SPI3A.Line (0, 0)-(Int(1200 * SPIO(3, 1)), 180), , BF
 SPI3B.Line (0, 0)-(Int(1200 * SPIO(3, 2)), 180), , BF
 SPI3C.Line (0, 0)-(Int(1200 * SPIO(3, 3)), 180), , BF
```

```
  CPI3O0.Caption = Format(CPIO(3, 1) * 100, "##0.000") & "%"
  CPI3O1.Caption = Format(CPIO(3, 2) * 100, "##0.000") & "%"
  CPI3O2.Caption = Format(CPIO(3, 3) * 100, "##0.000") & "%"
  CPI3A.ForeColor = QBColor(Barcolor)
  CPI3B.ForeColor = QBColor(Barcolor)
  CPI3C.ForeColor = QBColor(Barcolor)
  CPI3A.Line (0, 0)-(Int(1200 * CPIO(3, 1)), 180), , BF
  CPI3B.Line (0, 0)-(Int(1200 * CPIO(3, 2)), 180), , BF
  CPI3C.Line (0, 0)-(Int(1200 * CPIO(3, 3)), 180), , BF

Private Sub showoption()
  ' Select the option control to show

If file = 1 Then

  work1.Visible = False
  Mostgroup.Visible = False
  work2.Top = 1410
  Mediumgroup.Top = 1725
  work3.Top = 3600
  Leastgroup.Top = 3915

  timew1.Visible = False
  timew1.Left = 3255
  timew1.Top = 360
  costw1.Visible = False
  costw1.Left = 5350
  costw1.Top = 360
  qualityw1.Visible = False
  scopew1.Visible = False
  scopew1.Left = 7450
  scopew1.Top = 360
  clientw1.Visible = False
  humanw1.Visible = False
  materialw1.Visible = False
  spiw1.Visible = False
  spiw1.Left = 9550
  spiw1.Top = 360
  cpiw1.Visible = False
  cpiw1.Left = 11650
  cpiw1.Top = 360

  timew2.Visible = True
  timew2.Left = 3255
  timew2.Top = 990
  costw2.Visible = True
  costw2.Left = 5350
  costw2.Top = 990
  qualityw2.Visible = False
  scopew2.Visible = True
  scopew2.Left = 7450
  scopew2.Top = 990
  clientw2.Visible = False
  humanw2.Visible = False
  materialw2.Visible = False
  spiw2.Visible = True
  spiw2.Left = 9550
  spiw2.Top = 990
  cpiw2.Visible = True
  cpiw2.Left = 11650
  cpiw2.Top = 990

  timew3.Visible = True
  timew3.Left = 3255
  timew3.Top = 3180
  costw3.Visible = True
  costw3.Left = 5350
  costw3.Top = 3180
  qualityw3.Visible = False
  scopew3.Visible = True
```

```
  scopew3.Left = 7450
  scopew3.Top = 3180
  clientw3.Visible = False
  humanw3.Visible = False
  materialw3.Visible = False
  spiw3.Visible = True
  spiw3.Left = 9550
  spiw3.Top = 3180
  cpiw3.Visible = True
  cpiw3.Left = 11650
  cpiw3.Top = 3180

ElseIf file = 2 Then

  work1.Visible = False
  Mostgroup.Visible = False
  work2.Top = 1410
  Mediumgroup.Top = 1725
  work3.Top = 3600
  Leastgroup.Top = 3915

  timew1.Visible = False
  timew1.Left = 3000
  timew1.Top = 360
  costw1.Visible = False
  costw1.Left = 4700
  costw1.Top = 360
  qualityw1.Visible = False
  scopew1.Visible = False
  scopew1.Left = 6400
  scopew1.Top = 360
  clientw1.Visible = False
  clientw1.Left = 8100
  clientw1.Top = 360
  humanw1.Visible = False
  materialw1.Visible = False
  spiw1.Visible = False
  spiw1.Left = 9800
  spiw1.Top = 360
  cpiw1.Visible = False
  cpiw1.Left = 11500
  cpiw1.Top = 360

  timew2.Visible = True
  timew2.Left = 3000
  timew2.Top = 990
  costw2.Visible = True
  costw2.Left = 4700
  costw2.Top = 990
  qualityw2.Visible = False
  scopew2.Visible = True
  scopew2.Left = 6400
  scopew2.Top = 990
  clientw2.Visible = True
  clientw2.Left = 8100
  clientw2.Top = 990
  humanw2.Visible = False
  materialw2.Visible = False
  spiw2.Visible = True
  spiw2.Left = 9800
  spiw2.Top = 990
  cpiw2.Visible = True
  cpiw2.Left = 11500
  cpiw2.Top = 990

  timew3.Visible = True
  timew3.Left = 3000
  timew3.Top = 3180
  costw3.Visible = True
  costw3.Left = 4700
```

```
    costw3.Top = 3180
    qualityw3.Visible = False
    scopew3.Visible = True
    scopew3.Left = 6400
    scopew3.Top = 3180
    clientw3.Visible = True
    clientw3.Left = 8100
    clientw3.Top = 3180
    humanw3.Visible = False
    materialw3.Visible = False
    spiw3.Visible = True
    spiw3.Left = 9800
    spiw3.Top = 3180
    cpiw3.Visible = True
    cpiw3.Left = 11500
    cpiw3.Top = 3180

ElseIf file = 3 Then

    work1.Visible = False
    Mostgroup.Visible = False
    work2.Top = 1410
    Mediumgroup.Top = 1725
    work3.Top = 3600
    Leastgroup.Top = 3915

    timew1.Visible = False
    timew1.Left = 3100
    timew1.Top = 360
    costw1.Visible = False
    costw1.Left = 4800
    costw1.Top = 360
    qualityw1.Visible = False
    qualityw1.Left = 6500
    qualityw1.Top = 360
    scopew1.Visible = False
    scopew1.Left = 8200
    scopew1.Top = 360
    clientw1.Visible = False
    clientw1.Left = 9900
    clientw1.Top = 360
    humanw1.Visible = False
    materialw1.Visible = False
    spiw1.Visible = False
    spiw1.Left = 11600
    spiw1.Top = 360
    cpiw1.Visible = False
    cpiw1.Left = 13300
    cpiw1.Top = 360

    timew2.Visible = True
    timew2.Left = 3100
    timew2.Top = 990
    costw2.Visible = True
    costw2.Left = 4800
    costw2.Top = 990
    qualityw2.Visible = True
    qualityw2.Left = 6500
    qualityw2.Top = 990
    scopew2.Visible = True
    scopew2.Left = 8200
    scopew2.Top = 990
    clientw2.Visible = True
    clientw2.Left = 9900
    clientw2.Top = 990
    humanw2.Visible = False
    materialw2.Visible = False
    spiw2.Visible = True
    spiw2.Left = 11600
    spiw2.Top = 990
```

```
  cpiw2.Visible = True
  cpiw2.Left = 13300
  cpiw2.Top = 990

  timew3.Visible = True
  timew3.Left = 3100
  timew3.Top = 3180
  costw3.Visible = True
  costw3.Left = 4800
  costw3.Top = 3180
  qualityw3.Visible = True
  qualityw3.Left = 6500
  qualityw3.Top = 3180
  scopew3.Visible = True
  scopew3.Left = 8200
  scopew3.Top = 3180
  clientw3.Visible = True
  clientw3.Left = 9900
  clientw3.Top = 3180
  humanw3.Visible = False
  materialw3.Visible = False
  spiw3.Visible = True
  spiw3.Left = 11600
  spiw3.Top = 3180
  cpiw3.Visible = True
  cpiw3.Left = 13300
  cpiw3.Top = 3180

Else

  work1.Visible = True
  Mostgroup.Visible = True
  work1.Left = 795
  work1.Top = 780
  Mostgroup.Left = 165
  Mostgroup.Top = 1095

  work2.Top = 2355
  Mediumgroup.Top = 2670

  work3.Top = 3930
  Leastgroup.Top = 4245

  timew1.Visible = True
  timew1.Left = 2900
  timew1.Top = 360
  costw1.Visible = True
  costw1.Left = 4200
  costw1.Top = 360
  qualityw1.Visible = True
  qualityw1.Left = 5500
  qualityw1.Top = 360
  scopew1.Visible = True
  scopew1.Left = 6800
  scopew1.Top = 360
  clientw1.Visible = True
  clientw1.Left = 8100
  clientw1.Top = 360
  humanw1.Visible = True
  humanw1.Left = 9400
  humanw1.Top = 360
  materialw1.Visible = True
  materialw1.Left = 10700
  materialw1.Top = 360
  spiw1.Visible = True
  spiw1.Left = 12000
  spiw1.Top = 360
  cpiw1.Visible = True
  cpiw1.Left = 13300
  cpiw1.Top = 360
```

```
  timew2.Visible = True
  timew2.Left = 2900
  timew2.Top = 1935
  costw2.Visible = True
  costw2.Left = 4200
  costw2.Top = 1935
  qualityw2.Visible = True
  qualityw2.Left = 5500
  qualityw2.Top = 1935
  scopew2.Visible = True
  scopew2.Left = 6800
  scopew2.Top = 1935
  clientw2.Visible = True
  clientw2.Left = 8100
  clientw2.Top = 1935
  humanw2.Visible = True
  humanw2.Left = 9400
  humanw2.Top = 1935
  materialw2.Visible = True
  materialw2.Left = 10700
  materialw2.Top = 1935
  spiw2.Visible = True
  spiw2.Left = 12000
  spiw2.Top = 1935
  cpiw2.Visible = True
  cpiw2.Left = 13300
  cpiw2.Top = 1935

  timew3.Visible = True
  timew3.Left = 2900
  timew3.Top = 3510
  costw3.Visible = True
  costw3.Left = 4200
  costw3.Top = 3510
  qualityw3.Visible = True
  qualityw3.Left = 5500
  qualityw3.Top = 3510
  scopew3.Visible = True
  scopew3.Left = 6800
  scopew3.Top = 3510
  clientw3.Visible = True
  clientw3.Left = 8100
  clientw3.Top = 3510
  humanw3.Visible = True
  humanw3.Left = 9400
  humanw3.Top = 3510
  materialw3.Visible = True
  materialw3.Left = 10700
  materialw3.Top = 3510
  spiw3.Visible = True
  spiw3.Left = 12000
  spiw3.Top = 3510
  cpiw3.Visible = True
  cpiw3.Left = 13300
  cpiw3.Top = 3510

End If

End Sub

Private Sub Evidencehold()

 If EHOLD(1, 1) = 0 Then
  Call Timecw1_Click(0)
 ElseIf EHOLD(1, 1) = 1 Then
  Call Timecw1_Click(1)
 ElseIf EHOLD(1, 1) = 2 Then
  Call Timecw1_Click(2)
 End If
```

```
If EHOLD(1, 2) = 0 Then
 Call Costcw1_Click(0)
ElseIf EHOLD(1, 2) = 1 Then
 Call Costcw1_Click(1)
ElseIf EHOLD(1, 2) = 2 Then
 Call Costcw1_Click(2)
End If

If EHOLD(1, 3) = 0 Then
 Call Qualitycw1_Click(0)
ElseIf EHOLD(1, 3) = 1 Then
 Call Qualitycw1_Click(1)
ElseIf EHOLD(1, 3) = 2 Then
 Call Qualitycw1_Click(2)
End If

 If EHOLD(1, 4) = 0 Then
 Call Scopecw1_Click(0)
ElseIf EHOLD(1, 4) = 1 Then
 Call Scopecw1_Click(1)
ElseIf EHOLD(1, 4) = 2 Then
 Call Scopecw1_Click(2)
End If

 If EHOLD(1, 5) = 0 Then
 Call Clientcw1_Click(0)
ElseIf EHOLD(1, 5) = 1 Then
 Call Clientcw1_Click(1)
ElseIf EHOLD(1, 5) = 2 Then
 Call Clientcw1_Click(2)
End If

 If EHOLD(1, 6) = 0 Then
 Call Humancw1_Click(0)
ElseIf EHOLD(1, 6) = 1 Then
 Call Humancw1_Click(1)
ElseIf EHOLD(1, 6) = 2 Then
 Call Humancw1_Click(2)
End If

 If EHOLD(1, 7) = 0 Then
 Call Materialcw1_Click(0)
ElseIf EHOLD(1, 7) = 1 Then
 Call Materialcw1_Click(1)
ElseIf EHOLD(1, 7) = 2 Then
 Call Materialcw1_Click(2)
End If

 If EHOLD(1, 8) = 0 Then
 Call SPIcw1_Click(0)
ElseIf EHOLD(1, 8) = 1 Then
 Call SPIcw1_Click(1)
ElseIf EHOLD(1, 8) = 2 Then
 Call SPIcw1_Click(2)
End If

 If EHOLD(1, 9) = 0 Then
 Call CPIcw1_Click(0)
ElseIf EHOLD(1, 9) = 1 Then
 Call CPIcw1_Click(1)
ElseIf EHOLD(1, 9) = 2 Then
 Call CPIcw1_Click(2)
End If

If EHOLD(2, 1) = 0 Then
 Call Timecw2_Click(0)
ElseIf EHOLD(2, 1) = 1 Then
 Call Timecw2_Click(1)
ElseIf EHOLD(2, 1) = 2 Then
```

```
 Call Timecw2_Click(2)
End If

If EHOLD(2, 2) = 0 Then
 Call Costcw2_Click(0)
ElseIf EHOLD(2, 2) = 1 Then
 Call Costcw2_Click(1)
ElseIf EHOLD(2, 2) = 2 Then
 Call Costcw2_Click(2)
End If

If EHOLD(2, 3) = 0 Then
 Call Qualitycw2_Click(0)
ElseIf EHOLD(2, 3) = 1 Then
 Call Qualitycw2_Click(1)
ElseIf EHOLD(2, 3) = 2 Then
 Call Qualitycw2_Click(2)
End If

 If EHOLD(2, 4) = 0 Then
 Call Scopecw2_Click(0)
ElseIf EHOLD(2, 4) = 1 Then
 Call Scopecw2_Click(1)
ElseIf EHOLD(2, 4) = 2 Then
 Call Scopecw2_Click(2)
End If

 If EHOLD(2, 5) = 0 Then
 Call Clientcw2_Click(0)
ElseIf EHOLD(2, 5) = 1 Then
 Call Clientcw2_Click(1)
ElseIf EHOLD(2, 5) = 2 Then
 Call Clientcw2_Click(2)
End If

 If EHOLD(2, 6) = 0 Then
 Call Humancw2_Click(0)
ElseIf EHOLD(2, 6) = 1 Then
 Call Humancw2_Click(1)
ElseIf EHOLD(2, 6) = 2 Then
 Call Humancw2_Click(2)
End If

 If EHOLD(2, 7) = 0 Then
 Call Materialcw2_Click(0)
ElseIf EHOLD(2, 7) = 1 Then
 Call Materialcw2_Click(1)
ElseIf EHOLD(2, 7) = 2 Then
 Call Materialcw2_Click(2)
End If

 If EHOLD(2, 8) = 0 Then
 Call SPIcw2_Click(0)
ElseIf EHOLD(2, 8) = 1 Then
 Call SPIcw2_Click(1)
ElseIf EHOLD(2, 8) = 2 Then
 Call SPIcw2_Click(2)
End If

 If EHOLD(2, 9) = 0 Then
 Call CPIcw2_Click(0)
ElseIf EHOLD(2, 9) = 1 Then
 Call CPIcw2_Click(1)
ElseIf EHOLD(2, 9) = 2 Then
 Call CPIcw2_Click(2)
End If

If EHOLD(3, 1) = 0 Then
 Call Timecw3_Click(0)
ElseIf EHOLD(3, 1) = 1 Then
```

```
 Call Timecw3_Click(1)
ElseIf EHOLD(3, 1) = 2 Then
 Call Timecw3_Click(2)
End If

If EHOLD(3, 2) = 0 Then
 Call Costcw3_Click(0)
ElseIf EHOLD(3, 2) = 1 Then
 Call Costcw3_Click(1)
ElseIf EHOLD(3, 2) = 2 Then
 Call Costcw3_Click(2)
End If

If EHOLD(3, 3) = 0 Then
 Call Qualitycw3_Click(0)
ElseIf EHOLD(3, 3) = 1 Then
 Call Qualitycw3_Click(1)
ElseIf EHOLD(3, 3) = 2 Then
 Call Qualitycw3_Click(2)
End If

 If EHOLD(3, 4) = 0 Then
 Call Scopecw3_Click(0)
ElseIf EHOLD(3, 4) = 1 Then
 Call Scopecw3_Click(1)
ElseIf EHOLD(3, 4) = 2 Then
 Call Scopecw3_Click(2)
End If

 If EHOLD(3, 5) = 0 Then
 Call Clientcw3_Click(0)
ElseIf EHOLD(3, 5) = 1 Then
 Call Clientcw3_Click(1)
ElseIf EHOLD(3, 5) = 2 Then
 Call Clientcw3_Click(2)
End If

 If EHOLD(3, 6) = 0 Then
 Call Humancw3_Click(0)
ElseIf EHOLD(3, 6) = 1 Then
 Call Humancw3_Click(1)
ElseIf EHOLD(3, 6) = 2 Then
 Call Humancw3_Click(2)
End If

 If EHOLD(3, 7) = 0 Then
 Call Materialcw3_Click(0)
ElseIf EHOLD(3, 7) = 1 Then
 Call Materialcw3_Click(1)
ElseIf EHOLD(3, 7) = 2 Then
 Call Materialcw3_Click(2)
End If

 If EHOLD(3, 8) = 0 Then
 Call SPIcw3_Click(0)
ElseIf EHOLD(3, 8) = 1 Then
 Call SPIcw3_Click(1)
ElseIf EHOLD(3, 8) = 2 Then
 Call SPIcw3_Click(2)
End If

If EHOLD(3, 9) = 0 Then
 Call CPIcw3_Click(0)
ElseIf EHOLD(3, 9) = 1 Then
 Call CPIcw3_Click(1)
ElseIf EHOLD(3, 9) = 2 Then
 Call CPIcw3_Click(2)
End If

End Sub
```